Issued September 22, 1908.

U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF PUBLIC ROADS—BULLETIN No. 34.

LOGAN WALLER PAGE, Director.

DUST PREVENTIVES.

BY

PREVOST HUBBARD,

ASSISTANT CHEMIST, OFFICE OF PUBLIC ROADS.

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1908.

OFFICE OF PUBLIC ROADS.

LOGAN WALLER PAGE, Director.
ALLERTON S. CUSHMAN, Assistant Director and Chemist.
W. CARL WYATT, Chief Clerk.
VERNON M. PEIRCE, Chief Engineer.
J. E. PENNYBACKER, Jr., Chief of Road Management.
MAURICE O. ELDRIDGE, Chief of Records.
PHILIP L. WORMELEY, Jr., Testing Engineer.
BENJAMIN F. HEIDEL, Assistant Engineer.
PREVOST HUBBARD, Assistant Chemist.
EDWIN C. E. LORD, Petrographer.
A. E. DRAPER, Editor and Librarian.

Issued September 22, 1908.

U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF PUBLIC ROADS—BULLETIN No. 34.

LOGAN WALLER PAGE, Director.

DUST PREVENTIVES.

BY

PREVOST HUBBARD,

ASSISTANT CHEMIST, OFFICE OF PUBLIC ROADS.

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1908.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Public Roads,
Washington, D. C., June 5, 1908.

Sir: I have the honor to transmit herewith the manuscript of a bulletin on Dust Preventives, by Mr. Prevost Hubbard, Assistant Chemist in this Office. This subject is growing steadily more important, not only because of the great financial loss from the disintegration of expensive road surfaces which results largely from increased motor traffic, but also because of the annoyance resulting from excessive dust. I recommend that this manuscript be published as Bulletin No. 34 of this Office.

Respectfully,

Logan Waller Page,
Director.

Hon. James Wilson,
Secretary of Agriculture.

CONTENTS.

ILLUSTRATIONS.

PREFACE.

The rapidly growing interest and desire for information displayed by road engineers and others in matters pertaining to dust prevention and road preservation have lately become so manifest that it seems necessary to supply specific information in as comprehensive a form as possible, and, accordingly, this bulletin has been written with a view to meeting these demands. Few individual experiments have been mentioned, but the subject has been considered as a whole without entering into unnecessary detail. A careful review of all available literature on the subject has been made, and this has been supplemented by the results secured from actual experiments conducted by the Office. The problem of dust prevention and road preservation is not isolated, but is closely connected with all other problems pertaining to the construction, maintenance, and use of roads in general, and, so far as possible, these interrelations have been brought out in the following chapters. For instance, its connection with road construction is so pronounced that it seems safe to predict that the next ten years will see a decided change in the methods employed in building macadam roads.

The necessity for a more complete knowledge of the characteristic properties of dust preventives and road preservatives than has generally been shown by those who use them is so evident that considerable space has been devoted to their description. There is much yet to be learned, however, regarding the effect of certain properties of the materials used, and it is therefore impossible at the present time to present the subject exhaustively. In future experiments it is most desirable, whenever possible, not only that the experimenter carefully consider the composition and characteristics of the material employed, but that he accurately note these properties in any report that he may publish. By so doing he will materially assist in determining the effects of these materials.

Allerton S. Cushman.

DUST PREVENTIVES.

INTRODUCTION.

The suppression of dust on roads is a problem which has become prominent only within recent years, but its importance is rapidly increasing, as it involves the saving of much money and the comfort and convenience of the public at large, as well as of road users. It is the purpose of this bulletin not only to consider the causes of the formation of dust on highways, but to present the problem as it stands to-day and to indicate in a general way measures which have been taken to solve it.

In arriving at a complete understanding of a subject of this kind it is essential that as broad a view of it as possible be obtained, and, in order to achieve this result, one must look at the matter from at least three different standpoints—that of the engineer, the chemist, and the layman. The direct solution of the problem depends to a great extent, of course, upon the efforts of the road engineer, but, as will appear later, the aid of the chemist and road user will eventually prove to be important factors which can not be overlooked. The subject is one which also deserves the attention of the general public, as it has a very direct bearing upon matters which are of universal interest.

In considering the cause, or rather the causes, of dust formation a few general remarks may not be out of place. The term "wear," when applied to solid substances, undoubtedly expresses the fundamental cause of such formation, although other factors which make wear possible and which tend to remove and distribute the dust formed play important parts. All forces which tend to disintegrate or destroy will of necessity produce wear, and these forces, when considered in connection with roads, may be conveniently classed under three heads—chemical, physical, and mechanical. A detailed study of these subjects will be found in a number of publications by the Department.[a] The automobile is perhaps the most potent factor which at the present time operates to produce dust and destroy roads. When moving at a high rate of speed its broad rubber tires exert a

[a] U. S. Dept. of Agric., Bureau of Chemistry, Buls. 85 and 92; U. S. Dept. Agric., Office of Public Roads, Bul. 28.

pulling or lifting effect upon all loose material on the road surface and a cloud of dust is sucked up and carried along behind each vehicle. The slightest current of air then carries the dust cloud over the surrounding country. The enormous increase in the last few years of fast motor traffic along public highways has aroused general interest in the subject of dust prevention.

The coincidence of the appearance of the automobile with the aroused interest in the dust nuisance has led to the impression that the former is the sole cause of the trouble. It will be remembered, however, that the dust nuisance on a somewhat smaller scale existed long before the coming of the motor car. If the automobile has resulted in an awakened interest in this problem, it will have served a valuable purpose, but besides this it has undoubtedly exerted a beneficial influence in arousing the public at large to the knowledge that good roads are necessary to the welfare of any community, and thus has been instrumental in the construction of many miles of road which would otherwise have remained unbuilt.

CLASSIFICATION OF DUST PREVENTIVES.

The dust problem as it stands to-day seems to be open to two methods of attack—(1) by applying materials to the road which will hold down the dust formed, or (2) by methods of construction designed to reduce the formation of dust, and therefore the wear of the road, to a minimum. Dust prevention has so far been mainly confined to the treatment of old macadam surfaces, and many preparations have appeared on the market during the last few years for which great claims have been made.

There are also two general methods of preventing dust on finished surfaces—(1) keeping down the dust formed on the road and (2) reducing its formation to a minimum. With this classification in mind a corresponding division of dust preventives may be made, and the different materials may be classed as temporary binders and permanent binders. It will be found that this classification readily lends itself to a logical comparison of the relative merits of the different materials, when considered in regard to their application and suitability for different kinds of roads, as well as to various conditions of traffic and climate. The essential requisite for any dust preventive is its binding power, or, in other words, its power of holding together the fine material produced on the surface of the road. In order to keep down the dust, the temporary binders from their very nature will, of course, have to be applied with more or less frequency according as their properties approach those of the permanent binders. The term "permanent," as here considered, is only relative and applies to those materials which, upon one application, are capable of appreciably reducing the formation of dust for at least one season. Water, salt solutions, certain light oils and tars, and oil and tar emul-

FIG. 1.—AUTOMOBILE RAISING DUST CLOUD.

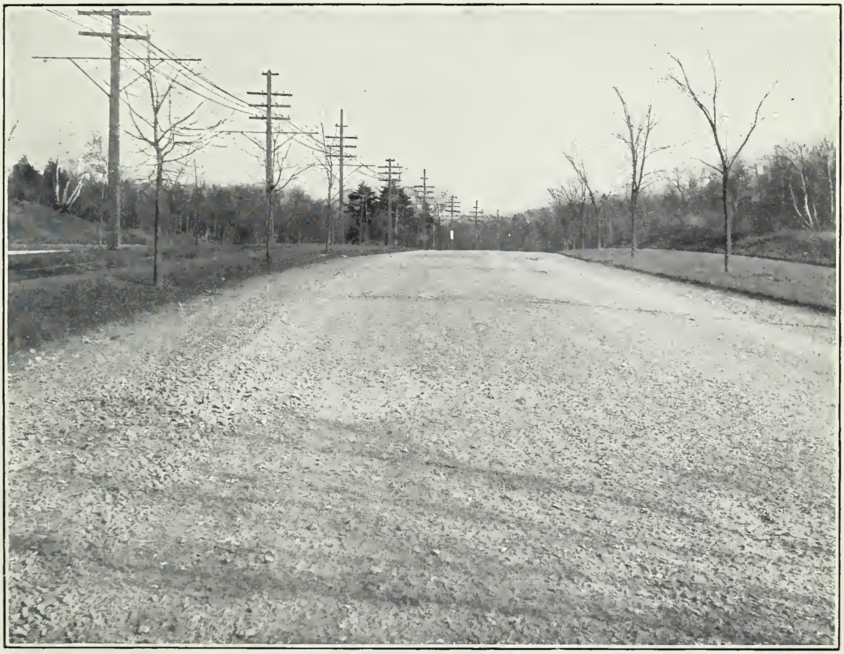

FIG. 2.—MACADAM SURFACE STRIPPED OF FINE MATERIAL BY AUTOMOBILE.

sions constitute the first class, while the heavier oils, tars, semisolid and solid materials represent the second class.

The value of the salt solutions commonly used lies in the hygroscopic character of the dissolved salt, which, having considerable affinity for water, keeps the road surface in a moist condition long after a surface treated with water alone would have become dry through evaporation. The light oils and tars, as well as the oil and tar emulsions, are dependent for their effect upon the retention by the road surface of a comparatively small amount of true binding base after the volatile products have evaporated. This base proves effective only so long as it retains its binding power. When the binding power is destroyed it is necessary to apply more material, and, if the base is an exceptionally good one, the accumulated products finally harden the road surface and prevent wear to some extent.

The heavy oils and tars differ from the lighter products in the fact that they contain a much greater amount of binding base. The results are therefore of a more lasting character from a single application and are productive of a better wearing surface, thus lessening to a considerable extent the formation of dust, even after they have become saturated with dust. The semisolid and solid preparations usually contain a still greater amount of binder and also other materials of a solid nature, such as rocks, sand, or clay. With some few exceptions, all of the true binders are bitumens, and these bitumens may be either natural or artificial.

In considering these materials individually, it has been found most convenient to take up the liquid preparations belonging to the second class first. In order to obtain a comprehensive understanding of the subject of dust preventives, it is essential that one should have at least some knowledge of the methods of manufacture or preparation of the various types, as well as of the chemical and physical properties of each. The next subject to be considered will therefore be the methods of manufacture and the properties of tars, which are the first binders with which we shall have to deal.

TARS, THEIR MANUFACTURE AND PROPERTIES.

Crude tars, as well as specially prepared tars and tar emulsions, have been used extensively for dust prevention ever since the subject was first seriously considered, and many experiments have been conducted with these materials in France, England, and the United States. The results obtained have to a great extent been contradictory, even when the experiments have been carried on in the same manner and under the same conditions, and for this reason much confusion has arisen in the minds of road engineers as to the real value of tars.

COAL TARS.

As a class, tars are liquid bodies obtained from the destructive distillation of such organic substances as wood, bone, and coal. They are of extremely complex composition, being for the most part mixtures of chemical compounds of the elements carbon, hydrogen, and oxygen, known as hydrocarbons and oxygenated hydrocarbons. In many cases other elements, such as nitrogen and sulphur, are also to be found in proportions which vary with the character of the original material, but these elements always occur in very much smaller amounts than the first three mentioned. Coal is by far the most important source of tar at present, and as coal tar is the material which has been most extensively used as a dust preventive, it will first be considered.

TAR FROM COKE OVENS.

While the production of tar is absolutely unavoidable in the manufacture of illuminating gas from coal, the same does not hold true in the manufacture of coke. In spite of the recent advance in the value of coal tar there are in this country to-day a great number of coke ovens in operation which make no attempt to recover any product other than coke from the coal, all of the volatile materials being allowed to escape. A number of ovens have, however, been designed with a view to saving or utilizing coke-oven by-products.

The oldest form of coke oven and one which is extensively used in this country to-day is known as the "beehive." It is constructed of brick and as its name implies has the form of an old-fashioned beehive. The coal is placed in this oven or kiln and a part of it is burned in order to carbonize the remainder, while the volatile products, such as gas, ammonia, and tar, are allowed to escape through an opening in the top of the kiln and are thus lost. Ovens in which the by-products are saved are now used to a slight extent in this country, but sooner or later will undoubtedly replace all of the old-style ovens and will thus enormously increase the output of tar. There are several forms of these new-style ovens, in which a coke suitable for metallurgical purposes is produced, the waste gas is employed to heat the retorts, and the ammonia and coal tar are recovered. Whichever oven is employed, the method is entirely analogous to that of gas manufacture, and stripped of all details the process is as follows: The coal is charged into long narrow chambers or retorts of about four or five tons' capacity and is heated by means of flues set in the retort walls. The volatile matter held in the coal passes out through an opening in the top and is conducted through a series of washers and scrubbers, as in the manufacture of gas, in order to remove the tar and ammonia. The purified gas is then allowed to pass into a holder

from which it is drawn as needed for burning under the retorts. For the sake of economy comparatively low temperatures are employed in these ovens, and this fact has an important bearing, which will be described later, upon the character of the tar produced.

TAR FROM GAS PLANTS.

In the manufacture of illuminating gas, bituminous coal is placed in specially constructed fire-clay retorts about 8 feet long, 15 inches high, and 18 inches wide. Six or eight of these retorts are set together in a furnace and constitute what is commonly known as a bench. A number of these benches built together is called a stack. The retorts are usually set horizontally or at a sufficient angle to allow of their being discharged easily, and are heated by means of a coke fire or by generator gas.

The tar which collects in the hydraulic main, the condensers, and the tar towers is run into large wells where it is allowed to settle for some time in order to separate it as far as possible from the accompanying ammoniacal liquor. The ammoniacal liquor being lighter than the tar rises to the top and can be drawn off. The crude coal tar which remains is a black viscid fluid of peculiar odor and varying in specific gravity from 1.1 to 1.2. As has been stated, it is an exceedingly complex mixture of chemical compounds and always contains a certain amount of ammoniacal liquor as well as several constituents of the illuminating gas in solution. It represents about 5 per cent of the weight of coal from which it is produced. The true tarry products are known as artificial bitumens in contradistinction to the natural bitumens found in various mineral oils and asphalts. The nature of the tar varies with the nature of the coal from which it is derived, and also with the conditions under which it is produced.

In its qualities as a road builder, by far the most important factor will be found in the temperature at which a tar is produced. In gas plants the attempt is, of course, made to produce as much gas as possible from a given quantity of coal, and therefore to distill at the highest practicable temperature. As the heat increases, the amount of gas produced also increases, but its illuminating power diminishes. This is due to the tendency displayed by the hydrocarbons to dissociate at high temperatures into their elements, hydrogen and carbon. Thus hydrogen will be produced as a gas and free carbon will be deposited in the tarry condensations; also the proportion of such substances as naphthalene and anthracene will be increased in the tar. The temperature maintained in the retort may be as low as 850° to 900° C., but will usually vary between these points and 1,100° C., or even higher, according to the quality of the gas which it is desired to obtain. As the value of coal tar as a dust preventive lies mainly in the binding power of the heavier bitumens contained in it, it is

evident that an excess of free carbon which has no binding value at all will prove detrimental. The same may be said of such substances as naphthalene and anthracene, and as these materials are produced in increasing amounts as the temperature is raised, it follows that the best results must be obtained by the use of tars produced at a low temperature. The reason for calling attention to the fact that tar from coke ovens is produced at a low temperature is now apparent, and when we consider that the actual bitumens present in a tar may vary from 60 to 95 per cent and the carbon from 5 to 35 per cent according to the temperatures employed in the retorts, the importance of ascertaining the chemical properties of the crude tar, or at least its method of manufacture, before purchasing it for use as a dust preventive is evident.

In reviewing descriptions of numerous experiments with this material it is of very rare occurrence to find one in which these properties are taken into account. It is not strange, therefore, that very different results from the use of crude coal tar are reported. It has been stated that crude coal tar contains as an impurity ammoniacal liquor, which is a solution of ammonia and ammonium salts in water. The presence of these salts, as well as the water, has been put forward as being the main objection to the use of crude tar; but while there may be some grounds for this opinion in comparing crude with refined tars, it does not satisfactorily explain the difference in results often obtained by the use of two crude materials. The effect of ammonium salts and water will be further discussed after taking up the next branch of tar manufacture, which is that of distillation or refining.

REFINED COAL TAR.

Much of the tar now produced is subjected to fractional distillation for the separation of certain constituents which are used in the arts. The residue left in the still is known as coal-tar pitch, and is a thick, viscous material while hot. It represents the true binding base of the tar, and if the tar is one produced at a comparatively low temperature, the residue is composed mainly of bitumens. After cooling for a few hours it is run out of the still and is graded as soft, medium, or hard, according to its condition when cold. The dead oils, which represent the heavier distillation products, and which are of less value than any of the other volatile distillates, are often run back into the still before the pitch is drawn off. In this case the pitch is liquid when cold. Besides the three grades mentioned there are numerous intermediate varieties which have their own particular use in the trades. Liquid pitch is often used as a paint for wood and metal work and for making tarred or roofing paper, while the harder pitches are employed as cements or mastics and find their place to a great extent in the paving industry in competition with the natural

bitumens, such as asphalt. If the coal tar has been previously manufactured at a high temperature, all of the free carbon or lampblack which was originally deposited on the tar will be found in the pitch. Its waterproofing and adhesive properties will therefore be very much lessened, and any preparation containing this pitch as a base will be correspondingly inferior for use as a dust preventive. If the distillation is carried too far, the pitch will become partially coked, which will considerably injure its binding qualities.

Naphthalene is one of the most important constituents of coal tar, and is consequently recovered from the various distillates. When pure it exists in shining white plate-like crystals, which volatilize very slowly at ordinary temperatures. It has a pungent, camphor-like odor, and is employed in the manufacture of moth balls. Its most important use, however, is in the preparation of coal-tar dyes. Its removal from the tar is undoubtedly of advantage in the preparation of a dust preventive, as it has none of the qualities requisite for a good material of this nature. The same may be said of anthracene, which is probably the most valuable constituent of coal tar and is therefore removed from the fractions in which it is found. It is employed entirely in the preparation of alizarine, a valuable coloring material.

In preparing a tar for use as a dust preventive most of the valuable products are removed by fractionation, and the least valuable products—that is, some of the carbolic and all of the dead oils—are run back into the pitch until about the same consistency is reached as that possessed by a heavy crude tar. Sometimes the addition of the dead oils from previous distillations is required to bring the mixture to this consistency. These oils give life to the tar, and, provided the percentage of pitch is not reduced too low, a mixture of this sort evidently has certain advantages over the crude tar, as it is comparatively free from naphthalene and anthracene and contains none of the light volatile oils and ammoniacal liquor found in the latter.

DEHYDRATED TAR.

Sometimes only dehydrated crude tar is prepared for dust prevention, the idea being to remove all water, ammonium compounds, and some of the light oils; and, if not too costly, a preparation of this kind is to be preferred to the crude tar. The absence of water makes it easier to handle when applied hot, and probably allows of a better absorption of the tar by the road surface. If much water is present in a tar the road material is apt to absorb it before the tar, and the road thus becomes, to a certain extent, tar-proof. As a result the tar is very likely to peel. Water in the tar itself will also hasten disintegration of the heavy binding materials. The ammoniacal

liquor may saponify some of the oily products which are then rendered capable of mixing with water and therefore are apt to be washed out. Dehydrated tar may be readily prepared by boiling the crude material in open kettles until its boiling point lies between 105° and 110° C. Great care must be taken, however, to prevent the tar from boiling over, as it has a strong tendency to foam while the water is being driven off.

WATER-GAS TAR.

Water-gas tar has also been used to some extent as a dust layer and road preservative. The principle of making water gas is based upon the decomposition of steam by incandescent coke or hard coal. The gas thus formed is composed of a mixture of hydrogen and carbon monoxide. As both of these gases burn with a nonluminous flame it is found necessary to enrich them with an admixture of hydrocarbons in order to produce a gas suitable for illuminating purposes. The enriching material commonly used is petroleum, and as the tar is derived from this substance, it is not uncommon to hear water-gas tar spoken of as oil tar. This oil tar is sometimes obtained in a similar manner from the manufacture of oil gas.

Without going into unnecessary detail it may be said that the true water gas is first obtained by admitting steam to a chamber called the generator which contains coke heated to incandescence. The water vapor reacts with this coke to form certain products and the mixture of gases is led into another chamber called the carburetor, where it meets a spray of hot oil, which is thus volatilized and carried on to still another chamber known as the superheater, where most of the hydrocarbons combine to form a permanent gas. The gas thus produced is washed with water and passed through extractors and scrubbers in much the same manner as ordinary coal gas, in order to remove the tarry products. It is needless to say that the character of the water-gas tar will vary with the kind and quality of oil employed, but in general it is a thin oily liquid of about 1.08 specific gravity containing from 2 to 10 per cent of water and having a strong gassy odor. It is entirely different in character from coal tar and contains a relatively small amount of heavy bitumens. The base is more or less thin in character and of poor binding quality in comparison with that held by a good coal tar. Water-gas tar may, however, be used to advantage as a dust preventive in certain instances and has the advantage of being cheap and easily handled It has been estimated that about two-thirds of the gas manufactured in this country is of the water-gas type. Comparatively few experiments have been made with it as a dust preventive, but from the few made it seems safe to say that the results obtained in any case will not be as lasting in character as from the use of coal tars. It does compare

quite favorably, however, with some of the lighter oils and oil and tar emulsions, as will be shown later. Its gassy odor soon evaporates on the road and is not permanently objectionable.

COMPOSITION OF TARS.

Three kinds of tar have now been described—crude coal tar, refined coal tar, and water-gas tar—and, as these are the principal ones used as dust preventives, their approximate composition in percentage volumes as determined from fair representatives of each type is given below for the purpose of comparison. The notes to the table refer to the condition of distillates and residues when cold.

Table I.—*Specific gravity and composition of tar products.*

Kind of tar.	Specific gravity.	Ammoniacal water.	Total light oils to 170° C.	Total dead oils, 170°–270° C.	Residue (by difference).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Water-gas tar	1.041	2.4	[a] 21.6	[b] 52.0	[c] 24.0
Crude coal tar	1.210	2.0	[d] 17.2	[e] 26.0	[f] 54.8
Refined coal tar	1.177	0.0	[b] 12.8	[g] 47.6	[f] 39.6

[a] Distillate mostly liquid.
[b] Distillate all liquid.
[c] Pitch very brittle.
[d] Distillate mostly solid.
[e] Distillate one-half solid.
[f] Pitch hard and brittle.
[g] Distillate one-third solid.

In many gas plants it is the custom to manufacture both coal gas and carbureted water gas. When this is done, the coal gas is produced at a high temperature in order to obtain the maximum amount, and the carbureted water gas is used to raise its illuminating value. The tar thus produced is a mixture of coal and water-gas tars and will usually be of an inferior quality for reasons before mentioned.

THE APPLICATION OF TARS.

There are two general methods by which tar can be used upon roads, one by applying it to the surface of the road and the other by constructing the road of tar-covered material. The application of tar to the road proper may itself be considered under two heads, and for the sake of convenience will be taken up in this way: (1) its application to the finished road, and (2) its application during construction.

APPLICATION TO FINISHED ROAD SURFACES.

As early as 1867 the process of spreading or painting road surfaces with tar was considered in France, but it was not until the year 1902 that work of this kind was begun in earnest. Crude coal tar was first tried, as it was easily obtained and comparatively cheap, but little attention was paid to its character and quality.

Most crude tars are too viscous to apply satisfactorily when cold, and the use of heat to render them more fluid has been generally adopted. The addition of a sufficient quantity of lighter oils will serve the same purpose, but a corresponding loss in the binding quality of the material will be produced by this dilution.

Experience has shown that in order to get the best results from applications of tar the road should be free from dust, perfectly dry, and comparatively warm. If dust and other fine material are present the tar will not be properly absorbed by the surface and, owing to a lack of bond, will soon peel and be removed by traffic. For this reason it can be applied successfully to hard surfaces only, such as are presented by well-swept macadam roads. The presence of moisture will also prevent the tar from penetrating the road, and as a cold surface will chill and stiffen the material it is necessary that all applications be made in dry, warm weather. Before applying the tar the road should be repaired where necessary, in order to secure as smooth and even a surface as possible. If ruts and hollows are present, the tarred road will not only present a poor appearance, but accumulations of water in these depressions will produce rapid disintegration of the tar, followed by its complete removal under the action of traffic. It is desirable that repairs be made for some time previous to the tar application in order to obtain a well-bonded and consolidated surface to start with, for it has been found that fresh patches which have been tarred are not unlikely to ravel if traffic is at all heavy.

The primitive method of application which has been largely employed in this country up to the present time is as follows: The road surface is first thoroughly swept in order to remove all dust. The hot tar is then spread on and thoroughly broomed in. The road should then, if possible, be closed to traffic and the tar allowed to remain untouched for about twelve hours in order to allow it to soak in. At the end of this time, or sooner if necessary, a coat of clean sand or stone chips should be applied to absorb the excess of tar, and the surface should then be rolled several times to bring it to proper condition quickly. The preliminary sweeping of the road is sometimes done by hand, but an ordinary mechanical street sweeper is often to be preferred, as it performs the work more economically and with greater expedition. The tar is heated in an open kettle preferably mounted on wheels and fitted with a portable fire box. It is usually brought to its boiling point—about 190° F.—before being spread upon the road, although a lower temperature is sometimes sufficient, and, if the kettle is of the type described above, the tar may be run out upon the road as required by means of a hose, the kettle being kept just in advance of the work. By using two kettles the process may be made continuous, one being charged and heated while the other is in use. Kettles holding easily 9 barrels, or about 450 gallons,

FIG. 1.—APPLICATION OF TAR TO MACADAM ROAD.

FIG. 2.—FINISHED TAR MACADAM. UNTREATED PORTION IN FOREGROUND.

of tar without danger of spilling over, and mounted on comparatively large wheels, are to be preferred for this purpose when long sections of road are to be treated. When it is impossible to obtain kettles mounted on wheels, a number of smaller ones holding about two barrels each are sometimes used. These kettles are moved along the side of the road as the work progresses and the hot tar is drawn off into flat-nosed watering pots, hods, or ladles, and spread by hand. In either case it is necessary to have the hot tar well broomed into the surface to obtain a smooth and uniform coat. This spreading is usually done by laborers with stiff, long-handled brooms, similar to those used in street sweeping, who follow the tar spreaders and broom carefully every portion of road surface. The excess of tar is thus pushed ahead and can be used for covering fresh surfaces.

After the tar has been spread it should be allowed to remain undisturbed for at least twelve hours, as has been stated. In cases, however, where it is impossible to keep traffic away for this length of time, one of two methods may be followed. Either one-half the width of the road may be covered at one time, thus allowing the other half to be open while the first is drying, or a coat of sand or fine stone chips may be applied at once in sufficient quantity to prevent the tar from sticking to the wheels of vehicles. If the first method is followed more lasting results are to be expected, but unless considerable care is taken the finished road will present a poor appearance owing to the overlapping of the second application on the first, which produces a seam along the center of the road. More time will also be consumed, as the length of the road will have to be gone over twice. If the second method is employed, there is danger of the tar being absorbed by the loose material rather than by the road proper, and this will result in a lack of sufficient bond. If the tar is allowed to remain undisturbed for about twelve hours it will, under ordinary conditions, be fairly well absorbed by the road, and then only enough top dressing need be applied to take up the surplus. Either clean coarse sand or one-half inch hard stone chips are to be preferred as a top course, as these afford a harder and better wearing surface than most other materials, such as road dust and gravel. It is customary to finish the road by rolling this fine material into the tar, but when only a light coating is applied the rolling may be unnecessary, as the action of traffic will in a short time produce the same result.

If the tar does not contain much heavy binding material and it is found necessary to patch the road during tarring, the addition of heated pitch to these patches will better tend to consolidate them and prevent them from being torn up by passing vehicles.

If the temperature of the crude tar is raised above 190° F. when being heated it is very likely to foam up, boil over, and catch fire.

Bad results which have been obtained from the use of crude tar are often charged to the presence of ammoniacal liquor, and it has become customary in certain localities to use only water-free tar. A good tar from which the ammoniacal water, light oils, naphthalene, etc., have been removed and the pitch diluted with a sufficient amount of the heavier tar oils to give a proper consistency should give the best and most lasting results. There are several preparations on the market which are claimed to have these qualities. They should not be taken on faith, however, but should be examined to see if they are really what they are claimed to be. The writer has examined different lots of some of these preparations and found essential and inexcusable differences to exist.

The application of tar by mechanical means may now be considered. Owing to the considerable expense involved and the time consumed in applying the tar from kettles, a number of schemes have been devised to apply it by means of various apparatuses. In France a specially constructed sprinkler has been used with some success, which can be manipulated by three men, and which, it is stated, will cover 3,000 square meters (3,280 yards) of ordinary roadway per day. Tar is pumped into a reservoir, and, after being heated by petroleum in a manner similar to that employed in heating the boiler of a steam-motor car, is sprayed upon the road by means of compressed air contained in an adjoining reservoir under a pressure of 5 kilos per square centimeter. If the road is first thoroughly swept and all remaining dust removed by means of a vacuum cleaner, the tar is expelled with sufficient force to penetrate well into the macadam, and therefore does not require brooming. A thin top dressing of sand should afterwards be applied to the tarred surface.

In England the application of tar by mechanical means has been studied by means of a trial competition of various machines carried on by a representative committee of engineers and others interested in road matters. Some exceedingly ingenious devices were produced at this contest, which give promise of good results. A number were designed to carry on the whole operation of tarring at one passage of the vehicle. Some are propelled by steam and so arranged that the road is first swept to remove the dust, which is drawn up by vacuum into a receptacle connected with the machine. The tar is heated and sprayed upon the road under considerable pressure, thoroughly broomed in, and the dust, previously removed, is distributed over the tarred surface. A full description of these machines has already appeared in print.[a]

Some attempts have been made in France to apply the crude tar cold and afterwards set fire to it. By this means it is claimed that

[a] Surveyor, 1907, **31**, Supplement, p. 67; Surveyor, 1907, **32**, 461.

the road surface is caused to absorb the tar to a considerable extent; and as the lighter oils will be consumed and the water and ammoniacal salts driven off, all of the advantages of applying a refined tar will be obtained. It is extremely doubtful, however, if this method will ever be extensively employed, as it seems entirely probable that some of the valuable binding materials will be burned and that the remainder will become brittle and useless on account of absence of oils which give the heavier products life. If the material is to be applied cold, it is far better to dilute it with the necessary amount of suitable oils, which, while lowering the percentage of true binding base, will nevertheless act as a dust layer until they are saturated or lost by evaporation. The advantages and disadvantages of applying tar in this way will be taken up later in a consideration of the other methods described.

USE OF TAR IN ROAD CONSTRUCTION.

So far we have dealt only with the methods of applying tar to a finished surface. Where a new road is under process of construction, or an old road is being resurfaced, it is often desirable to apply the tar in a somewhat different manner. In these cases the road should first be shaped and consolidated as well as possible without the addition of water. The voids should be well filled with clean fine stone chips free from dust, but an excessive amount of rolling should be avoided in obtaining this condition. If the roller is used too freely the larger stones will become rounded and covered with dust, which prevents the tar from adhering properly. Hot tar may be applied to all of the courses if desired, but sometimes only the upper course is so treated. After the tar has been applied a dressing of fine material is spread on in the manner described in the other methods of application and the whole road is well rolled. A road so treated will have all of its interstices filled with hard material and only sufficient tar to surround each individual particle. Thus all wear will be sustained by the stone aggregate and the tar will act solely as a binder. It will be seen that a road so constructed will approach very closely the road built of material which has been previously tarred.

If the tar is applied by hand, a great deal more will be taken up by the road than is absolutely required. As this means an unnecessary expense, attempts have been made to devise a method which will produce good results with a minimum amount of tar. A tar spreader similar to those already described has been tried with some success for this purpose in England and in Scotland. A brief description of this apparatus and the method of using it may serve to illustrate the most important points relative to a treatment of this kind. The spraying apparatus is mounted on wheels and is so arranged that the tar is forced from the tank in which it is heated

into an air receiver under a pressure of from 150 to 350 pounds per square inch. The necessary power for pumping the air and the liquid into the receiver is obtained by means of a chain drive from the road wheel of the vehicle. From the receiver the tar is distributed upon the road by means of specially designed spraying nozzles.

In considering the relative value of these different methods of application and the character of the material which will give the most satisfactory and economical results, it is necessary to take into account many factors which have a most important bearing on the subject. There is probably no one practical and economical method which can be used under all conditions, but there are certain facts which have been demonstrated that will serve as a guide in ascertaining the proper method to follow under given conditions. Many of the results obtained have, as has been pointed out, been undoubtedly influenced by causes which were not given sufficient consideration, but the general characteristics of roads treated with tar in different ways have been ascertained and should be understood.

A properly tarred road after being subjected to traffic for a short time closely resembles asphalt. It is smooth and firm, of a more resilient character than asphalt, and is practically noiseless. While in good condition it is to a great extent waterproof and almost dustless; and, if the proper amount of tar has been applied, the resistance to traction is less than that of an untreated macadam road. If too much tar has been applied, the road is apt to become soft and sticky in warm weather, thus causing a notable increase in the draft of vehicles, and it is also apt to rut badly. A few days after application almost all objectionable odor will disappear. Decayed vegetation, prolonged rains, and frost are the worst enemies of the tarred road.

The tar retains its hygienic and germicidal properties for some time. To determine this point, an investigation of the relative number of living germs existing in the atmosphere just above a tarred and an untarred road in the same neighborhood was made in France by Christiani and Michelis. They found less than one-half the number in the former case as in the latter, both in damp and dry weather.

AMOUNT AND COST OF MATERIALS.

The amount of tar required to treat a road will depend upon the fluidity of the material when applied and the absorbing power of the road. Soft rocks, such as limestone and dolomite, will take up more tar than granite or trap and will in general give better results owing to the greater penetration of the tar and stronger bond formed in consequence. According to conditions and methods of application, a surface-treated road will require from 0.35 to 0.70 gallon of tar per

square yard when application is made by hand. When applied by machine as small an amount as 0.21 gallon has been used with good results for a first treatment. With either method the application of tar must be repeated from time to time, though less is required at each successive application. If the tar is applied as the road is built as much as 1.5 gallons per square yard is often consumed if application is made by hand. By means of devices like the pneumatic tar sprayers, described on pages 18, 19–21, however, it is claimed that the road stones to the depth of 3½ inches may be well covered by the application of about 0.6 gallon per square yard.

Crude coal tar varies in price according to locality, but it can ordinarily be purchased from gas or coke companies at from 3 to 5 cents per gallon. The price of the refined tars runs from 6 to 12 cents per gallon and even higher. On account of this difference in price the use of a good crude tar is often to be preferred.

The cost of treatment for a surface-tarred road will, of course, depend upon a number of factors. In France, when done by machine, it will average about 3 cents, and when done by hand 5 cents per square yard. In this country, where it is generally applied by hand, the cost is hardly ever less than 6 cents and in a great many cases as high as 12 cents and more per square yard. This is largely due to the poor condition of our roads before treatment, which necessitates the application of more tar and more surface dressing than if they were in good condition in the first place. The cost of tarring a road during construction is very hard to estimate. In England it is claimed that the pneumatic tar sprayer will apply the tar at a cost of about $5 per mile of 18-foot roadway exclusive of the cost of the tar. It is needless to say that this figure would be greatly increased if the tar were spread by hand.

It has been stated that on account of its cheapness a crude tar is sometimes to be preferred to a refined material. In very severe climates, however, where a single application of tar is unlikely to last through the winter, it would seem advisable to apply a tar which has been diluted with dead oils or with water-gas tar in order to give it sufficient fluidity to apply cold. In this way the cost of application will be greatly reduced, and although the percentage of true binding base will be somewhat lessened, the results should under the conditions named be satisfactory. Where a road is being tarred during resurfacing or during the process of construction it is very essential that the tar contain a large proportion of binder. The use of a properly refined tar is certainly to be preferred to the crude material in this instance. While water-gas tar may be used to dilute the heavier tars, it can hardly be considered in the same class owing

to its lack of true binding material. It, however, readily finds its place in competition with the lighter oils and emulsions.

Before leaving the subject of applying tar to macadam roads, those built of material which is tarred before being placed on the road should be briefly considered, at least in so far as the properties and application of the tar itself are concerned.

The tarred material may either be applied as a surface dressing to an old or new road or the whole road may be built of such material. Owing to the consistency of the tar or pitch usually employed, it is absolutely necessary that it be heated before applying, and in some cases the road stone should also be heated. It is evident that, within certain limits, the greater the proportion of pitch contained in the tar the firmer will be the bond produced. As very stiff pitch, however, exhibits a tendency to chip when cold, it is advisable to use one which contains enough of the heavier tar oils to give it life and maintain its resiliency. Attention should also be paid to the composition of the pitch with respect to its free carbon content. The same general methods are employed as those which have already been described.

On account of its hardness and porosity, blast-furnace slag is particularly suitable for work of this sort, and has been extensively used in England. The construction of asphalt macadam similar to tar macadam has also been suggested, and natural sandstone impregnated with asphalt has been employed in some localities.

In dealing with an old macadam road the application of a 3 or 4 inch course of tarred stone to the freshly cleaned surface has in some cases proved a success. If crude coal tar is used it should be thickened with a considerable quantity of pitch in order to give it the proper binding qualities, and in a case of this sort it is well to cover the old surface with a light application of hot tar, in order to secure a good bond between it and the new course.

One of the most promising roads of this type is constructed according to what is known as the Gladwell method. The old road is first covered with a matrix composed of tar and stone chips. Broken stone is then applied to the depth of 4 inches and the road well rolled. By this means the tar matrix is forced upward and binds the broken stone firmly together. A surface application of tarred chips, which should be well rolled, gives the road the proper finish.

OILS, THEIR CLASSIFICATION AND PROPERTIES.

Oils as a class are fatty organic substances derived from innumerable sources. They may be most conveniently divided under three heads, as animal, vegetable, and mineral. While oils of the first two classes have been used to some extent as dust preventives, mineral oils are by far the most important, and have been most gen-

erally used for this purpose. As animal and vegetable oils, owing to their lack of heavy binding bases, may be ranked as temporary binders, they may be considered most conveniently with the lighter mineral oils and emulsions, which will be taken up later.

As in the case of a tar, the value of an oil as a permanent dust preventive lies in the quality and quantity of high-binding bituminous base retained by the road surface after evaporation of the more volatile constituents. The bases present in petroleums vary from those of almost pure paraffin to almost pure asphalt, many being mixtures of the two. While the paraffin oils are of much more value than the asphalt from a commercial point of view, the opposite is true from the standpoint of their use in dust suppression. An oil wholly paraffin is of value only as a temporary binder or dust layer, while an asphalt oil, owing to the character of the base contained, ranks with coal tar as a permanent binder. Like coal tar, petroleum is a mixture of a great number of organic bodies known as hydrocarbons, together with small quantities of sulphureted, nitrogenized, and oxygenated compounds. The approximate composition of crude petroleum is ordinarily determined by distillation, but a knowledge of the residuums left after distillation is of far more value from the standpoint of dust suppression. Considerable attention has been paid to these residuums, as well as to the characteristics of oils from the various fields by Richardson, who in a recent paper[a] has published the results obtained by himself and other investigators. It is this classification that will be followed in considering the value of different oils as dust preventives.

OIL FIELDS OF THE UNITED STATES, AND CHARACTER OF THEIR PRODUCTS.

There are seven distinct oil fields in the United States, which yield oils differing in qualities. The Appalachian, which includes the States of New York, Pennsylvania, West Virginia, southeastern Ohio, and parts of Kentucky and Tennessee, produces oils which are known as eastern oils or paraffin petroleums, and which are therefore of use only as temporary binders in dust suppression. The Ohio-Indiana field produces oils which are much like those of the Appalachian and are also classed as paraffin oils; and the same is true of the Colorado oils. The Wyoming oils vary in character from the lighter to the heavy asphaltic oils which are found principally in California. The oils from the California field, while of the most varied character, consist mainly of more or less dense asphaltic hydrocarbons. None of the components are of the paraffin series, and, as the percentage of asphaltic residue in these oils is usually

[a] Richardson, Clifford. VI. Congresso Internationale Di Chimica Applicata, Roma, 1906, Comunicazione fetto nella Segione IV.—A (Industrei dei prodotti organici.)

high and of a good binding character, they may be considered the best for use as permanent binders. Oils from the Texas field are of a mixed character. All of them contain some paraffin as well as a greater or less amount of asphaltic residue. Some have been used successfully as dust preventives, while others are unfit for this purpose. It is needless to say that their value lies in the relative amounts of asphaltic and paraffin base contained. The Kansas oil field, including Oklahoma, produces oils quite similar to those from the Texas field and shows a mixed paraffin and asphaltic base. The Louisiana field also yields oils similar to the Texas. Some of the wells in the Indiana and Kentucky fields have also been successfully used. In general, however, the eastern oils are of the paraffin type and useless as permanent binders; the western oils are of asphaltic character and of great value as permanent binders, while the southern oils are of a mixed character, containing part paraffin and part asphalt bases, their value as dust preventives lying in the relative amount of asphalt base contained.

METHODS OF REFINING AND CHARACTER OF RESIDUUMS.

While crude oil has been used to a great extent in the West for the purpose of dust prevention, it is often customary in the East to partially distill oils containing asphaltic residues before using them in this connection. By this means many of the more valuable constituents are recovered and the residual oils produced have a much better binding quality, owing to the fact that they contain a larger percentage of asphaltic base. As a knowledge of the methods of manufacture of tars was shown to be of considerable importance to the intelligent road builder when dealing with the problem of dust prevention by tar application, so a knowledge of the methods of preparation of the residual oils is of value to one who has occasion to do similar work with these products. A brief description of the principal processes of oil refining and of the properties possessed by different types of refined oils will therefore be given.

Crude petroleum is an oily liquid of rather unpleasant odor, with a specific gravity ranging from 0.73 to 0.97, according to the locality from which it is derived. It varies in color from greenish brown to nearly black and often exhibits a reddish brown or orange color when viewed by transmitted light. It is also somewhat fluorescent. Sand and water are often mixed with the crude oil, but these separate and settle upon standing in the storage tanks. In order to recover various products from the crude petroleum, it is subjected to a process of refining by means of fractional distillation in a manner somewhat similar to that employed for the refining of crude coal tar.

The most valuable products are the kerosene, or burning oils, and a method known as "cracking," which increases their yield, is very

generally employed. This is accomplished at a certain stage of the distillation by modifying the fire so that only the bottom of the still is subjected to a great heat, while the top and sides, being exposed to the air, become somewhat cooled. By this means the heavy oil vapors are condensed within the still itself, and upon dropping back into the residuum, which is much hotter than their boiling point, break up into lighter oils with lower boiling points with a separation at the same time of free carbon or coke, which is deposited in the residuum. Here we have a condition somewhat similar to that encountered in the case of coal tar produced at a high temperature. As the free carbon is not a binder, it is useless in a dust preventive, and when present in large amounts is apt to produce the same bad effects in an oil as in a tar.

The residuums of the various petroleums have been used to a great extent as fluxes for softening the solid native bitumens used in the paving industries. Their various characteristics and properties have therefore been given considerable study. As the character of the residues present in both the crude and refined petroleums is of the greatest importance from the standpoint of dust suppression, the results obtained from a study of these fluxes should be of service in determining the suitability of various oils for this purpose. The character of the residue will naturally vary as the crude petroleums vary, although, as has been shown, the method of preparation may produce considerable effect upon the residue.

The paraffin petroleum residuums are of a soft, greasy character and, as their name implies, contain a large amount of paraffin hydrocarbons and paraffin scale or crude paraffin. A road surface treated with material of this character will be dustless for the time being, but in damp, rainy weather will become covered with a slimy, greasy mud, which is easily washed away and leaves the road in as bad, if not worse, condition than it was before treatment. When the crude or even the residual oil is used solely as a binder, it may therefore be predicted that the outcome will prove a failure.

The base held by the California petroleums is composed of bitumens resembling asphalt. The residuum contains no paraffin and, if cracking has not been employed in its preparation, carries but little free carbon. The specifications for California fluxes call for not over 6 per cent fixed carbon. Both the crude oil and the residuums, if properly prepared, act as excellent binders and have, as a rule, given the best results of any oils which have been used as dust preventives.

The semiasphaltic oils, such as those obtained from Texas, carry an asphaltic base, but also a considerable amount of paraffin hydrocarbons and a little over 1 per cent of paraffin scale. While somewhat inferior to the California products, good results have often

been obtained from their use on roads in both the crude and the refined state. Those which contain the greatest amount of heavy binding bitumens and the least amount of paraffin scale are, of course, to be preferred. In order to obtain the best results the residuums, as well as the crude oils of asphaltic or semiasphaltic character, should be comparatively free from water.

Sometimes the residues from the distillation of petroleum while yet hot are subjected to the action of a jet of air, which has a tendency to thicken or harden them. It is doubtful, however, if an oil thus treated will be improved for use as a dust preventive, as the life of the oil is apt to be destroyed and its lasting qualities as a binder lessened.

The use of a paraffin petroleum is just as much to be avoided as a high-temperature tar, and in both cases a good crude product is to be preferred to a badly cracked residuum or one produced from a poor quality of crude material. Considerably more attention has been paid to the actual quality of oils which have been employed as dust preventives than to tars, although the latter have perhaps been more extensively used. A number of specially prepared or refined oil products are now on the market for use on roads, both in the form of residuums and emulsions. The residuum products have been prepared from asphaltic or semiasphaltic oils by methods similar to those described, while the emulsions are usually residuums which have been treated with saponifying agents in order to make them miscible with water.

COMPARISONS OF CRUDE OILS AND RESIDUUMS.

Owing to the fact that oils from a number of wells are commonly run through the same pipe lines from the wells to the storage tanks, it is often difficult to obtain two lots of oil having exactly the same properties, even when purchased from the same source. It is very important, therefore, that an examination of each lot of oil be made before attempting to use it for the purpose of dust prevention. Sometimes a partial chemical analysis is necessary, but in the majority of cases a few simple tests will determine its suitability for this purpose. These methods of examination are described on pages 58–60. It is also a wise measure to examine residuums even when they are especially advertised as road preparations, for, as has been stated, there is a strong tendency among refiners to crack their oils in order to increase the yield of illuminants, and when this is done the value of the residuum for the purpose of dust prevention will be considerably lessened. If the road engineer understands thoroughly the properties possessed by the oil which he is handling, he will be able to avoid many dismal failures which might otherwise occur.

Some of the results obtained from an examination of various crude and refined petroleums in the New York Testing Laboratory are given in the following tables in order to show the differences in properties possessed by the different kinds of material. They do not in any sense represent absolute values for the different classes of oils but will serve to give a general idea of the relative characteristics of each.

TABLE 2.—*Results of tests of crude petroleums.*

Kind of oil.	Specific gravity.	Flashing point.	Volatility at 110° C., 7 hours.	Volatility at 160° C., 7 hours.	Volatility at 205° C., 7 hours.	Residue.
		°C.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Pennsylvania, paraffin	0.801	([a])	47.3	58.0	68.0	[b] 32.0
Texas, semiasphaltic	.904	43	20.0	27.0	49.0	[c] 51.0
California, asphaltic	.939	26	....	....	[d] 42.7	[e] 57.3

[a] Ordinary temperature.
[b] Soft.
[c] Quick flow.
[d] Volatility at 200°, 7 hours.
[e] Soft maltha; sticky.

It will be noticed from the foregoing results that in the samples examined the specific gravity increases from the paraffin to the asphaltic oil. This is also true of the percentage of residue, while the volatility decreases correspondingly. The residues range in character from soft and probably greasy through an intermediate and but slightly viscous stage to the more or less liquid maltha of good adhesive properties. A rough idea of the character of these bases may be formed by rubbing a little of the residue or even of the crude oil between the finger and thumb. Those of a paraffin nature will feel greasy, while those of an asphaltic character will often exhibit an adhesiveness which is easily distinguishable. The color and odor will also indicate the character of the crude material to those familiar with the different varieties. In comparing the Pennsylvania with the Texas oil, it will be seen that the former carries a higher per cent of light oils than the latter. A comparison of the residuums obtained from refining oils similar to those described in Table 2 is shown in the following table:

TABLE 3.—*Results of tests of petroleum residuums.*

Kind of oil.	Specific gravity.	Flashing point.	Volatility at 200° C., 7 hours.	Residue.	Solid paraffin.	Fixed carbon.
		°C.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Pennsylvania, paraffin	0.920	186	14.2	[a] 85.8	11.0	3.0
Texas, semiasphaltic	.974	214	6.2	[a] 93.8	1.7	3.5
California, asphaltic	1.006	191	17.3	[a] 82.7	0.0	6.0

[a] Soft.

In comparing these results an increase in specific gravities in the same direction as in the case of the crude petroleums will be noticed. The volatility and percentage of residue, however, are not in the same

order. As these are dependent entirely upon the point at which distillation is stopped in the process of refining, such a result is to be expected. The percentage of solid paraffins is found to decrease to zero as the character of the oil becomes asphaltic. Only 11 per cent was found in this particular sample from Pennsylvania, but it is not uncommon for oils of this nature to carry as high as 33 per cent paraffin. The amount of fixed carbon is found to increase with the asphaltic character of the oil, and this fact is quite general, owing to the greater tendency of the asphaltic oils to crack during distillation.

In comparing the crude oils with the residuums it will be seen that the latter, as would naturally be supposed, carry a greater percentage of residue, and, other things being equal, are therefore of more value as permanent binders. A considerable difference is also seen to exist between their flash points, which is the temperature at which their most volatile products flash when brought in contact with a flame. As a general rule it is not difficult to distinguish between a crude and a residual oil, but in cases where any doubt may exist the flash point is a fairly accurate indicator. Thus, in the case of the crude Texas oil and the Pennsylvania residuum, we find that their specific gravities are quite close together, and some doubt might exist as to which was crude and which residual. A determination of their flash points would at once settle this question.

THE APPLICATION OF THE HEAVIER OILS.

As in the case of tars, many valuable facts have been learned in regard to the application of oils to road surfaces, although, owing to contradictory results, considerable differences in opinion seem to exist as to the actual and relative values of different kinds of oils under the same conditions and under varying conditions. This is, to a great extent, due to lack of knowledge in regard to the properties of the material used and to the fact that climatic conditions and the character of the road treated have a much more important bearing upon the results than is usually realized.

The subject of oil application, unlike that of tar, has received considerably more study in our country than has been given it by European nations. It is true that various experiments have been carried on in England and France with a number of different oils, but owing to the lack of a proper base in these oils the results have been discouraging. Shale oils and Russian petroleum residuums, known as "masut" or "astatki," have been employed, as well as certain vegetable oils, such as oil of aloes. They have all been found effective as temporary dust preventives, but in rainy weather produce a greasy, disagreeable mud and soon disappear from the

road surface. The best results have so far been obtained with heavy oils applied in the form of a spray while hot.

As the application of the temporary binders or lighter oils can best be considered in connection with that of oil emulsions, the application of the heavier oils only will be taken up here. Crude petroleum as well as residuums and specially prepared oils have been used with more or less success on earth and gravel roads, as well as on stone roads, and in this respect have an advantage over tar, which so far has given good results on hard roads only.

APPLICATION TO MACADAM SURFACES.

In applying oil to a macadam surface the same general methods are employed as in the application of tar. Holes and inequalities should be repaired; it has not been found necessary to remove all dust from the road surface so carefully as in the case of tar, but sticks, leaves, and other detritus of an organic nature should be removed.

The crude or refined oil may be applied either cold or hot, according to its viscosity and ability to penetrate the road surface. The application of cold oil is considerably the cheaper and is to be preferred on that account. Most crude oils and some of the lighter residuums have been used in this way with good results, but it has been found necessary to heat the heavier products before application.

If much work of this kind is to be carried on in one locality, it is sometimes the custom to erect a stationary heating plant at a convenient railroad siding. A plant of this sort has been described in a previous publication,[a] and consists of a receiving tank of one tank-car capacity placed preferably so that the oil may be run in by gravity from the car. A heating tank set at an elevation sufficient to allow the hot oil to run into the distributing wagons and fitted with steam coils through which superheated steam may be forced is placed near the receiving tank. The oil may be pumped into this heating tank as required and heated to any desired temperature. Very often the heating is carried on in the tank car, and the hot oil run directly into the distributing wagon. When sufficiently fluid, it can then be applied to the road by means of a large pipe and broomed into the surface in the same manner as tar. Patented distributing devices have been employed which can be attached to almost any form of tank wagon and which, if the oil is fluid enough, will do away with the necessity of brooming. An oil applied by this means will, however, have to be heated to a higher temperature than in the former case, as the openings in the distributer are of small dimensions and will not allow the oil to pass freely if it is in a very viscous state.

---

[a] Use of Mineral Oil in Road Improvement, Yearbook Dept. Agric., 1902, p. 446.

As in the case of tar, the main object is to obtain an even coating, which shall be well absorbed by the road surface. The application of a large excess of oil should be avoided, as it is sure to make the surface sticky and disagreeable. A covering of sharp sand or one-half-inch stone screenings should be applied after the oil has been allowed to penetrate as much as possible, in order to take up all excess, and the surface thus formed should be rolled until well compacted, additional sand or screenings being thrown on wherever the oil shows a tendency to force its way to the surface and produce a sticky condition. Sometimes two or three courses of oil and screenings are applied. It is usually considered better to allow the freshly oiled road to dry out to some extent before applying the top dressing, but in cases where it is impossible to keep traffic away the same methods may be employed as in the case of tar, i. e., either one-half the width of the road may be treated at one time or the sand or screenings may be applied at once. If the oil is well absorbed it is not always necessary to employ the roller, as ordinary traffic will consolidate the surface in the course of time.

APPLICATION DURING CONSTRUCTION OF MACADAM ROAD.

The application of oil during process of construction has been carried on with the greatest success in California, where the heaviest asphaltic oils are found. The residuums obtained from the partial distillation of these oils have so far given the best results when properly applied. The treatment is essentially the same as with tar, the object being to build a road containing a low percentage of voids, so that the oil will act as a binder only and the strain of traffic be borne by the road stone. Considerable attention should be paid to proper drainage of the road, as it is essential that the foundation be perfectly dry. The macadam is built in the usual manner and each course thoroughly rolled until the whole road is well consolidated. If water is used during the process of construction sufficient time should be given for the road to become perfectly dry before applying the oil. The hot oil is applied by means of a tank wagon fitted with a distributing device which insures an even distribution. Any excess of oil is taken up by the application of a sufficient covering of sand and screenings, and the road is then opened to traffic.

A road constructed in this manner will usually require from $\frac{3}{4}$ to $1\frac{1}{2}$ gallons of oil per square yard, depending upon the quality of oil employed and kind of road surface treated.

As in the case of tar work, the softer and more porous rocks, such as limestone, permit of a better penetration than the harder rocks, such as trap and granite, but good results have been obtained by the use of both kinds. Oils as a class seem to penetrate better than tars, as they do not harden as quickly upon exposure to the air. In order

to keep the road in proper condition, repairs should be made as often as necessary, and in the same manner as in the case of tars. By this means rapid disintegration will be prevented, which would otherwise occur if water were allowed to accumulate in the worn places.

APPLICATION TO GRAVEL ROADS.

A gravel road is oiled in much the same way whether it is an old road or one under construction, as only the upper course is treated in either case. It is especially important in a road of this kind that the drainage be good, and this matter should be attended to first of all. Any holes or pockets which may exist should be cleared out, if much fine material is present, and filled with clean, fresh gravel, so that the surface of the road will be uniform when the patches have been sprinkled and rolled. If the lateral drainage is bad, the entire surface should be loosened and brought to proper grade and crown by the addition of new material before the oil is applied. In this case more oil will be required to effect a good bond than if the old-compacted surface was treated, but the results will be of a more lasting character. The oil may be applied either cold or hot, according to its viscosity, by any of the methods already described. It should contain a high percentage of good asphaltic base, or otherwise the material near the surface will become loose, owing to the lubricating qualities of the oil. The use of too much oil should be especially avoided, and all excess should be taken up by the addition of fresh gravel. Where the surface treated is loose and contains a considerable amount of clay, the oil may be worked into the upper course by raking, which insures an equal distribution. After application of the oil, the road should be rolled until properly compacted, and as this is apt to bring some of the oil to the surface, fresh material should be added where necessary. If the freshly oiled road is not well rolled, the action of traffic will bring the oil upward; a soft spongy surface condition will be produced; loose, oily particles will be thrown out by rapidly moving vehicles; and the oil will be tracked by pedestrians.

Oil is applied to a gravel road during construction in a manner quite similar to that already described, but certain points in regard to the method of construction should be noted. These facts are well presented by the commissioner of the department of highways of California[a] in a report which contains specifications used in certain parts of that State for the construction of oiled graveled streets. As California has been most successful in this kind of work, a study of the methods used there should be of great value to experimenters in other localities. Certain portions of these specifications in condensed

[a] Biennial report, 1906.

form are given below for the purpose of emphasizing the most essential points.

Before placing the gravel the subsurface must be brought to grade and rolled. Upon this subsurface two layers of good gravel should be applied, the bottom layer having a thickness of 5 inches and the top a thickness of 3 inches after being rolled. The first layer should contain no stones larger than $2\frac{1}{2}$ inches in greatest diameter. The gravel must be uniformly spread on the roadway and well moistened, rammed 1 foot from the gutter or curb, and the remaining portion rolled with a roller of the type before specified. All depressions must be promptly filled, moistened, and again rolled, the rolling being continued until the surface will not yield under the roller. On this surface the top layer of gravel, free from all stones larger than 1 inch in greatest diameter, should be applied and compacted in the same manner as the first layer. Oil should then be evenly distributed over the entire surface at the rate of one-half gallon per square yard, and covered with clean, sharp sand until no oil can be seen. After the lapse of not less than twelve hours, another application of oil should be made and sand distributed in the same manner and the whole surface rolled until unyielding to the roller, as before described.

These specifications require that the oil be crude and that it be applied at a temperature not less than 150° F. nor above 190° F. Certain methods of testing the properties of the oil are included in the specifications, and a consideration of these tests will be found on pages 58–60. In regard to measuring the petroleum, however, it may be said that the volume at 60° F. is taken as normal, and a deduction of 0.1 per cent is made for every 10° increase over this normal temperature as a correction for expansion by heat.

USE OF OIL ON EARTH ROADS.

The use of oil on earth roads was first tried in this country in California. Crude petroleum was sprinkled upon the road for the purpose of laying the dust only. It proved to be a very effective dust layer, and in some cases improved the condition of the road surface to such an extent that popular attention was aroused, and as a result many experiments were made with a view not only to laying the dust, but to hardening the surface. Since then oil has been used with varying success and failure, and much valuable information has been derived from the experiments. California is particularly favored for work of this nature, owing to its climate and the character of its roads, as well as to the excellent road-building properties of its oils. Although it is impossible to duplicate these conditions in other localities, the lessons learned from the numerous

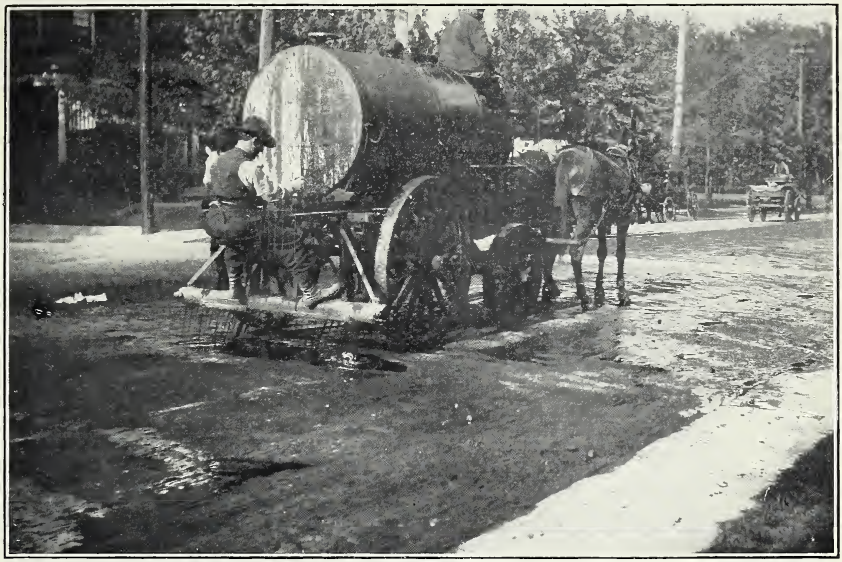

FIG. 1.—APPLICATION OF OIL TO MACADAM SURFACE.

FIG. 2.—FAST-MOVING AUTOMOBILE ON OILED ROAD RAISING NO DUST.

experiments conducted in this State are of great interest as offering suggestions for work of a similar nature in other places.

It has been found that the character of the soil plays a most important part in the results obtained, and different kinds of soils have to be treated in different ways. Alkali soils disintegrate the oil and destroy its binding qualities. A sandy loam is the most suitable for treatment, and almost invariably gives good results when treated in the proper manner with an oil of good binding quality. From a physical standpoint clay is probably the worst of all, as it does not absorb the oil well and exhibits a tendency to ball up and give trouble. Sand should therefore be added to the clayey surface until this difficulty is overcome. As in the case of gravel roads, special attention should be paid to drainage, and the roadbed should be dry when the oil is applied. If the foundation is water-soaked, it soon loses its ability to support the surface properly, which will then break through in weak spots.

The use of too much oil should be avoided, as it will produce a spongy surface condition and increase the draft of vehicles to a considerable extent. It is most important to keep a road thus treated in good repair. Whenever a rut or hole develops it should be cut out, oil should be poured in, and it should be filled up with good earth or sand. The loose material should then be thoroughly tamped until even with the surrounding surface.

Besides the method of oiling earth roads already described, another has recently been employed with considerable success in California. This method differs from the other in two essential particulars. The first of these is that water is applied during the process of oiling, and the second that consolidation is produced by a special tamping device. The method has given satisfactory results with sand and clay roads, as well as with loam and gravel, and is conducted as follows:

The road is first plowed up to the depth of 6 inches and properly crowned. All clods and lumps are then thoroughly broken up by means of a harrow, and the roadway is well sprinkled with water. A specially constructed rolling tamper is then used by which the lower portion of the loose earth is compacted to a depth of about 2 inches, except in cases where the subgrade is unusually firm.

After the lower portion is made firm by this means a heavy asphaltic oil is applied at the rate of about $1\frac{1}{2}$ gallons per square yard, and a cultivator is passed over the road until the oil and earth are thoroughly mixed. The tamper is then used again, and the road is further compacted until only $1\frac{1}{2}$ inches of loose material remain on top. This is lightly harrowed and sufficient water is added to moisten it. Oil is again applied, and the surface is rolled with the tamper until firm, and finally it is ironed down with an ordinary

roller, additional applications of earth being made wherever necessary to take up any excess of oil.

A road constructed in this manner will require from $2\frac{1}{2}$ to 3 gallons of oil per square yard. It is hard and dustless and resembles asphalt.

The California oils are best adapted for this method of road building, but the cost of transportation to the Eastern States at the present time raises the price to a prohibitive figure. The Texas and some of the Kentucky oils are the best available for these localities, and range in price from about 4 to 8 cents per gallon, according to locality. The residuums and special preparations vary from 2 to 12 cents per gallon. It is impossible to estimate cost of application except for individual cases; but, in comparison with cost of tar application, it would seem that where both products can be obtained close at hand oil is usually somewhat cheaper.

The natural enemies of the tarred road are also enemies of the oiled road. All kinds of properly oiled roads are dustless, noiseless, waterproof, and resilient, and offer but little resistance to traffic. The crude oils have a rather unpleasant odor, which soon passes away. Both the crude and residual oils exhibit a somewhat weak germicidal action. If an excess of oil is present upon the road surface, an oiled mud is formed in wet weather which is damaging to clothes and the paint on vehicles, but this condition is not met with if the proper amount of the right kind of oil is employed.

WATER, AND SALT SOLUTIONS.

The temporary binders as previously defined are materials which have to be applied at more or less frequent intervals in order to suppress dust. Their primary object is to lay the dust only, although they may also tend to preserve the road from wear. No distinct line can be drawn between the permanent and the temporary binders, but in general the latter class may be said to embrace water, salt solutions, the lighter oils and tars, and various emulsions. Some of these materials, however, approach the permanent binders quite closely and can be considered in either class, according to the method employed in their application.

USE OF WATER ON ROADS.

Water is undoubtedly the first material that was ever used for the purpose of laying dust. During hot, dry weather its use has never been satisfactory, owing to its rapid evaporation. Frequent and heavy applications are often required to keep the dust down, and in many localities where the traffic is heavy it is practically impossible to obtain good results by the use of water alone. The cost of frequent sprinklings with water is a considerable item; and when the

fact is taken into account that at the end of a season but little permanent benefit has been derived from its use, it will be seen that dust laying by this method is by no means economical. When heavy applications are made the road is apt to be gullied. With certain rock powders, or rock dusts, water will react to form either colloidal or crystalline binding materials, but these binders are not in themselves capable of withstanding the combined attack of ordinary and automobile traffic, and when these conditions have to be met the use of some substance other than water alone is to be preferred.

USE OF SALT SOLUTIONS.

The principal action of water in laying dust consists in the mechanical bond produced by the force of capillarity when two wet surfaces are brought in contact. The action of certain salts may increase the formation of binding material to some extent, but as a rule they are not used primarily for this purpose.

It has long been known that certain salts have so great an affinity for water that they are not only capable of retaining moisture for a long time under conditions which would otherwise produce rapid evaporation, but that they are capable of absorbing water from the atmosphere to a great extent. Some of the salts are so hygroscopic that in a humid atmosphere they will often completely dissolve in the water which they have absorbed from the air. Salts of this character are termed deliquescent, and it is to a great extent these hygroscopic and deliquescent salts which have been employed as dust preventives. By their use the roadway is kept in a semimoist condition for a much longer period than by the application of a corresponding amount of water only, and the number of sprinklings necessary is therefore greatly reduced.

USE OF SEA WATER.

One of these salts, magnesium chloride, occurs to a considerable extent in sea water. The effect of its presence in the cheaper grades of table salt may be seen in the tendency exhibited by the salt to clump in damp weather. This is due to the absorption of water by the small amount of magnesium chloride which remains even after the salt has been purified. On account of the presence of this substance, sea water has been tried in a number of favorably situated localities for the purpose of laying dust. While the number of sprinklings has been somewhat reduced by this means, the results have, as a rule, been far from satisfactory, owing to the presence of an excessive amount of common salt (sodium chloride), which is applied at the same time and which has no hygroscopic properties. In extremely dry weather a hard, salty scale is produced on the road which is very undesirable, and in wet weather the mud contains so much salt that

it is injurious to the varnish and ironwork on vehicles. This strong salt mud is also apt to cause soreness around the fetlocks of horses.

In the process of manufacturing ordinary salt from sea water a waste product is obtained which is known as "bitter brine," or bittern. This bittern is the mother liquor remaining after most of the sodium chloride has been crystallized out by evaporation. It is rich in magnesium chloride, and therefore more suitable for road use than ordinary sea water. As it is worthless for other purposes, its cost is very low and in certain localities its use might prove economical. Its application for the purpose of laying dust is covered by patent. So far, no very extensive use has been made of this substance, but, as it is apt to contain a considerable amount of inert sodium chloride, the same objections which have been urged against the use of sea water might be applicable here, although to a much less extent.

USE OF CALCIUM CHLORIDE.

Calcium chloride, which is obtained for the most part as a by-product in the manufacture of soda, has been used to a considerable extent as a dust layer. It is more hygroscopic than magnesium chloride and can be obtained at a moderate price in an almost pure state. It is sold either in solution or in a solid, fused, or granular condition. The solid material contains about 25 per cent moisture and 75 per cent calcium chloride, while the solutions run from a saturated condition to various weaker strengths. The ordinary concentrated solution carries about 40 per cent calcium chloride and has a specific gravity of 1.400. Both the solid and solutions are sold on a basis of the actual salt content, and the solid is therefore cheaper when the cost of transportation is taken into account. It can at the present time be purchased at about $16 per ton f. o. b. at points of manufacture.

Calcium chloride has been used to a slight extent in the United States for the purpose of laying dust, and when properly applied has proved successful. The amount of salt and number of applications required to keep down the dust satisfactorily for a season will vary greatly with local conditions, but the exercise of a little judgment makes it possible to obtain good results with a minimum expense. Before considering its advantages and disadvantages, however, its method of application should be taken up.

In most cases it is applied for the first time on the unprepared road. The solution is sprinkled from an ordinary watering cart, so that on an average 0.4 gallon is applied per square yard, although by regulating the spread of the sprinkler to about two-thirds the width of the road the middle receives twice the amount of the sides when the sprinkler passes over the road twice. While the center receives a double application by this means there is a tendency for

the whole surface to receive an equal share, owing to the fact that rains tend to carry the dissolved salt to the sides of the road. A 15 or 20 per cent solution is first employed, and at least two of these applications are made in the first week or two in order to impregnate the surface thoroughly with the salt.

The salt thus applied has a tendency to retain moisture for a considerable length of time after an ordinary application of water would have evaporated. On hot dry days, however, the road does dry out, especially on portions unprotected by shade, and it has been found necessary to feed the salt by ordinary applications of water. The number of sprinklings necessary will, however, be greatly reduced. It is, of course, cheaper to feed the calcium chloride already on the road with water than to apply a fresh solution each time the road becomes dry. In humid weather it is often unnecessary to apply water for days at a time, as the salt absorbs sufficient moisture from the damp night air to keep the road in good condition throughout the succeeding day.

In the course of time much of the calcium chloride is washed out of the road and has to be replaced by fresh material. Single applications of an 8 or 10 per cent solution, applied at intervals varying from two to five weeks apart, according to conditions, are usually sufficient to maintain the proper amount, and these may be made in the same manner as described for the first two. A too rapid drying of the road is an indication that more salt is needed, and a little experience will soon enable the overseer or experimenter to determine just how often and at just what time to make a fresh application. The same is also true with respect to feeding the salt with water.

In regard to ascertaining and regulating the strength of solutions, the most convenient method is to determine its specific gravity by means of a hydrometer. Accurate determinations have been made of the specific gravity of solutions of known percentage composition, and, as hydrometers graduated to direct specific gravity readings can be obtained, the method is a very simple one. A hydrometer graduated from 1 to 1.4 is most suitable for ordinary work, and by comparing the readings with the following table the strength of solution can be immediately ascertained. Also by diluting the salt, or a concentrated solution with water, any desired strength may be obtained if the dilution is stopped at the specific gravity indicated for that particular strength.

Specific gravity of salt solutions containing given percentages of salt.

Per cent calcium chloride	5	8	10	15	20	30	40
Specific gravity	1.041	1.068	1.086	1.132	1.181	1.286	1.402

A method has lately been devised and patented for diluting and distributing materials miscible with water, which has many advantages as a time and labor saver. As this method is applicable to both salt solutions and emulsions, it may be well to describe it at this point. A watering cart is used similar to the ordinary type, with the exception of a rack attached to the rear, which is capable of holding a nest of five or six galvanized iron cans, each having a capacity of over 100 gallons. The wagon is capable of holding about 600 gallons. The cart is first loaded with the concentrated material which is to be diluted. It is then driven to the first hydrant along the road. Here a quantity of the material sufficient to give the desired strength when diluted to the capacity of the wagon is drawn off into one of the cans. The wagon then proceeds to the next hydrant, where another lot is likewise unloaded, and so on. If the wagon has previously been loaded with a quantity equal to some multiple of the charges drawn off, a point will at last be reached where a quantity equal to that held by the separate cans remains in the wagon. Enough water is then run in from a hydrant to fill the wagon and the solution thus produced is applied to the road. Upon returning the empty wagon is refilled at each of the hydrants beside which a can of the material has been left, the empty cans being returned to the rack. A siphon arrangement, controlled by the water flowing from the hydrant, serves to lift the preparation into the wagon together with the water, thus producing the desired mixture. By employing a method of this sort many unnecessary trips of the wagon are avoided and the cost of handling is reduced to a minimum.

Where a considerable amount of work is to be done with calcium chloride the concentrated solution may be prepared or stored in large tanks set at an elevation sufficient to allow it to be run into the watering cart by gravity. Some time is required to dissolve the solid material, and, if it is not possible to secure a reservoir, the material should either be dissolved in the watering cart over night or else in the cans which should have been previously distributed at the different hydrants.

The principal advantages of calcium chloride as a dust layer are that it is odorless and clean. When present in sufficient quantity it is undoubtedly a good dust layer if the atmosphere is somewhat humid, or if it is fed occasionally with water in dry weather. While it is true that the formation of mud in wet weather is not lessened, this mud is no more objectionable than that ordinarily encountered, as not enough salt is present to give it the undesirable qualities produced by the application of sea water. In addition, calcium chloride tends to distribute the moisture evenly over the road sur-

face and it can be easily and quickly applied. Its use, like that of any other good dust layer, prolongs the life of a road by retaining the products of wear, and in some cases it may by chemical action increase the cementing value of the rock powder.

On the other hand, it is not essentially a road builder, and at the end of a season's treatment, while the road may be in better condition than at the start, no additional wearing material will be present. Heavy rains are likely to wash most of it from the road, and if a number of showers follow soon after an application much of its value will be lost. Water does not, however, always carry away as much of the salt as might be supposed, owing to the absorbent qualities of many rock powders. Another objection to its use is that in hot dry weather it requires feeding with water sometimes as often as once a day. In common with all other temporary binders which are applied in solution or emulsion, it can only be employed in localities favored with a convenient water supply.

As a rule, it is slightly more expensive than water alone, but when applied intelligently according to a system similar to that described, the cost of treatment is in some measure reduced. In one case, under severe traffic conditions on a macadam road, the cost of laying the dust for one season was reduced from 3 cents per square yard with water alone to 2.7 cents with the use of calcium chloride. Six applications were made—two in June and one each in July, August, September, and October—and on very dry days the road was given one light sprinkling with water. From this treatment the dust was successfully laid throughout the season, while in previous seasons four applications of water a day often proved ineffective. Under certain conditions, therefore, calcium chloride may not only prove to be a good dust layer, but economical as well. And even if the cost is somewhat greater than for the application of water alone, the beneficial effects produced upon the road will, in many cases, more than compensate for this difference.

OTHER SALTS USED IN DUST PREVENTION.

There are a number of other salts, or salt preparations, which have been used to some extent as dust preventives, among which might be mentioned a mixture of nitrate of soda, sodium chloride, and lime. The use of sodium silicate, known as water glass, has also been suggested on account of its tendency to react with some of the mineral constituents of road rocks to form hard insoluble binding products. An application of a sodium silicate solution followed by one of an aluminum or calcium salt by which insoluble silicates of alumina or lime are formed on the road proper has also been suggested.

THE TEMPORARY TAR AND OIL BINDERS, EMULSIONS, AND SIMILAR PREPARATIONS.

Two types of temporary binders—water, and salt solutions—have already been considered, and we now come to a third type, represented by the tars and oils. For the sake of convenience these latter materials will be considered under two headings, according to the condition in which they are applied. The first class will comprise those materials which are applied in their natural state, and the second those which are applied in the form of water emulsions. Materials of both classes are most easily and satisfactorily applied by means of an ordinary watering cart and usually upon the unprepared road. As in the case of water and salt solutions, a number of applications at more or less frequent intervals is generally necessary to lay the dust for a season.

MATERIALS APPLIED IN THEIR NATURAL CONDITION.

Among those materials which are applied in their natural condition are some which exhibit no actual road-building qualities, while others are to be found which contain a relatively small quantity of the substances which have been considered in preceding papers as permanent binders. The former act merely as palliatives and lay the dust in much the same manner as water, by wetting, or, in this case, oiling the dust particles to such an extent that they are held together by force of capillarity. Vegetable oils, paraffin petroleums, and certain tar oils, such as the heavy, dead, or creosote oils, belong to this class of materials. Their effect is of longer duration than that of water owing to the fact that they evaporate much more slowly. Like water, they have a definite point of saturation for the dust particles, and when this point is passed the road again begins to grow dusty. If they are present in too great an amount, a soft, greasy surface condition is produced, which is very undesirable. Heavy rains are apt to wash them out of the road, and the presence of water upon road surfaces to which they have been applied is productive of an oily, disagreeable mud under the action of traffic, and pools of oily water form in any ruts or depressions which may exist. They have been tried in many places, and, while they have proved to be fairly efficient dust layers, the disagreeable results produced in wet weather and the fact that they do not improve the road permanently has brought their use into general discredit.

The oils and tars which contain a certain amount of true binding base are much to be preferred for the purpose of dust laying to the materials just described. While for the most part they volatilize slowly, they nevertheless leave behind upon evaporation some binding material which is not removed by water and which tends to harden and bind together the surface cushion of fine material. Successive

applications result in an accumulation of this binding material, and at the end of a season's treatment a very noticeable improvement in the wearing quality of the road surface is found to exist, and in some cases the resulting condition is similar to that produced by a single application of a permanent binder containing the same kind of base. A material of this kind holds an intermediate position between the palliatives and the permanent binders and possesses some of the qualities of each. The volatile oils, constituting by far the greatest portion, act through force of capillarity to lay the dust, and when they are evaporated or become saturated another application is required. At the same time the true binding base present actually cements some of the loose particles together and, as it works into the road proper, produces the results already described. If too heavy an application is made at one time the road surface will become soft and greasy and easily rutted, or if an appreciable amount of a nonbinding base, such as paraffin, is present, as in the case of some semiasphaltic petroleums, the same disagreeable mud will be formed in wet weather as that produced by the oil palliatives. Besides being disagreeable, this mud is ruinous to clothes and the paint and varnish on vehicles. In both cases the oil is apt to prove injurious to rubber tires.

Water-gas tar, which has been described on p. 14, is perhaps one of the best temporary binders that can be applied in its natural state, although it has not been very generally employed. It can be obtained for about 3 cents a gallon, and when applied at the rate of 0.3 gallon per square yard on an ordinary macadam road will lay the dust successfully for some time. The number of applications required during a season will, of course, depend upon various conditions, but under ordinary circumstances a comparatively few will suffice. This material is readily absorbed by the road, and contains a sufficient amount of pitch to reduce dust formation to a considerable extent. It has a rather objectionable gassy odor, which, however, soon disappears. When used on roads having a great amount of fine material it is sometimes necessary to apply more than 0.3 gallon per square yard. In a case of this sort the tar does not bind the dust down firmly to the underlying surface, but it holds the particles well together and keeps them from being raised by passing vehicles or winds. Under the action of traffic this loose or shifting surface is alternately compacted and broken up, but it does not form a disagreeable mud. During rainy weather, in fact, it has been known to produce a compact, uniform surface, which appears to advantage in comparison with the surface in dry weather. In localities where water-gas tar can be readily obtained with but little cost for transportation it can undoubtedly be used to advantage, and in

many cases should successfully compete with other temporary binders.

Besides water-gas tar some of the lighter semiasphaltic oils in their crude condition may be applied as temporary binders, as has already been indicated. When not too much paraffin is present, the residue left upon the road after the volatile constituents have evaporated forms a permanent binder. Successive applications will therefore result in a condition similar to that obtained by the single application of a heavy asphaltic oil, and the wearing quality of the road will be improved. As an example of a preparation insoluble in water which may be employed in its original condition might be mentioned a mixture of creosote, shale, or other mineral oil and coal tar.

In regard to method of application, it may be said that in general the best method of applying to a road surface this kind of material or, in fact, any temporary binder is the same as that described for calcium chloride; that is, the middle of the road is given twice as heavy treatment as the sides, owing to the tendency of the material to be carried to the sides by gravitation and by running water. Of course the system described under the subject of calcium chloride for diluting concentrated material is only applicable to those substances miscible with water, as in the case of emulsions, which will next be considered.

EMULSIONS OF OILS WITH WATER.

Emulsions of oils or fats with water may be made either by mechanical or chemical means.

Chemical emulsions have up to the present been most generally used for the purpose of dust prevention, but before considering them it may be well to mention an apparatus which has recently been devised for the purpose of spreading a mechanical mixture of oily substances and water upon a road surface. This is a cart with two tanks, one containing the oil or tar and the other containing water. These two substances are led through pipes into a box where they are thoroughly mixed by means of rapidly whirling blades, which also force the mixture upon the road in the form of a spray. The water either evaporates or is rapidly absorbed by the road, thus leaving the tar or oil in a fine film over the surface, where it acts both as a binder and a dust layer. The number of applications required during a season will, of course, depend upon the character of the binder and quantity employed at each application, as well as upon local conditions. This method of application has proved satisfactory in some English experiments, but it has so far not been employed to a sufficient extent to warrant a general recommendation. It has some advantages over the chemical method of forming emulsions which will now be described.

Chemical emulsions are oily substances made miscible with water through the agency of saponifying materials. These saponifying materials react with a part of the fats or oils to form more or less soluble soaps, solutions of which are capable of mixing with oils and tars. Alkalies, such as potash or soda, are probably the most widely known saponifying agents, but other substances may be employed for the same purpose. Ammonia and also crude carbolic acid have been used to a considerable extent in preparing emulsions for the purpose of laying dust. In some cases no direct saponifying materials have been added to the oily material, but cheap soap solutions have been used instead. A number of these oil and tar emulsions have appeared on the market during recent years, and many have given good results when properly applied.

It is quite impossible to describe all of these preparations, as the exact composition of most of them is kept secret by the manufacturers. A few simple mixtures which are typical of these preparations will, however, be presented in order to give a general idea of their properties, method of application, and the results obtained from their use. In preparing an article of this sort, it is usually the endeavor of the manufacturer to produce a material which will contain the maximum amount of binding material per unit volume and at the same time be economical. Waste products from the various arts can frequently be utilized in these preparations, and of course tend to cheapen the material. Deliquescent substances, such as calcium chloride and certain soluble resinates, are sometimes incorporated in the preparations for the purpose of retaining moisture, while in others certain chemicals are employed for the purpose of oxidizing or hardening the binder upon evaporation of the volatile constituents. Before taking up the separate types in detail, it may be said in regard to their application that all are dependent upon a convenient water supply. As it is necessary to dilute them before using, a method similar to that described for calcium chloride, by which portions are first distributed at the different hydrants along the road, is the one which is likely to prove most economical.

The first type of emulsion which will be considered is the asphaltic or semiasphaltic oil emulsion, which has in this country undoubtedly been used to a greater extent than any other. In some of our large cities these emulsions have been prepared under the supervision of the experimenter, in which case a soap solution has generally been employed to emulsify crude oils containing asphaltic bases. In other cases special preparations have been purchased which contain a residual asphaltic or semiasphaltic oil emulsified by means of saponifying agents.

In Boston a number of the park roads are treated with an emulsion prepared as follows: To every 50 gallons of water 18 pounds of

cotton-seed oil soap, costing $4\frac{1}{2}$ cents per pound, are added, and the solution is hastened by the application of steam heat. This solution may be made in barrels and afterwards pumped into the sprinkling wagons or into a reservoir. One hundred gallons of crude petroleum is then added to every 50 gallons of soap solution and the mixture is agitated until emulsification is complete. The emulsion thus produced contains about 66 per cent oil and is considerably diluted before applying to the road. The percentage of asphaltic base will of course depend upon the amount contained in the original oil. A 16 per cent oil solution is applied to the road at first and the succeeding applications vary from 5 to 10 per cent, according to the needs of the road. The number of applications required during a season will vary with conditions. They are usually made, however, from ten to twenty-five days apart. By the use of a soap emulsion of this kind the loose material on the road is held down, but is not bound firmly together nor to the road surface. A thin rolling cushion is produced, saturated with oil, which prevents dust formation and protects the underlying surface. A very light coating of sand or fine stone screenings is sometimes spread on the road before applying the emulsion. This produces a cushion which will be hard and firm and take a considerable amount of wear. The main objection to this thin rolling cushion is that under the action of traffic it is apt to be worked to the sides of the road and finally into the gutters. It is then necessary to throw the old material back or apply fresh material, and this of course requires constant attention and considerably increases the cost of the work. In certain cases the cost of applying sufficient emulsion to lay the dust for a season has been as low as 2 cents per square yard, as compared with the cost of watering in previous seasons of 3 cents per square yard. The cost of applying sand and throwing back material which is carried to the gutters should, however, be added to this in order to obtain the actual cost of maintaining the road in proper condition. Except for a rather faint oily odor, no unpleasant results are obtained from an emulsion of this sort. The principal advantage is its cheapness, which is due to the fact that it is manufactured by the experimenter. It has been found that if too much is applied at one time an undesirable loose scale is formed when the surface dries out. This is undoubtedly due to the soap used, which to some extent destroys the true binding value of the asphaltic base, owing to the presence of fixed alkalies. Light applications at more frequent intervals are therefore to be preferred. As shown by experiments conducted on park roads in Chicago with soap and oil emulsions, a number of factors have to be taken into account when preparing the emulsion. The selection of soaps will be regulated to some extent by the character of the water used, and an oil or oil mixture should be obtained which will properly emulsify

with the soap solution. Where the water is hard, a naphtha soap has been found to give the best results.

When for any reason it is inconvenient to install an emulsifying plant, asphaltic-oil emulsions may be purchased which are already prepared in concentrated form. One of these which has been used with good results consists of a heavy Texas residuum emulsified by the addition of ammonia, crude carbolic acid, and creosote, which is incorporated with the oil under the action of heat and agitation. As an emulsion of this sort carries a high percentage of asphaltic binder, it can be diluted considerably before applying. One of these preparations which was examined by the writer was found to contain about 60 per cent of good asphaltic base after most of the volatile constituents had been removed. The quality of the oil employed is, of course, a very important factor in the binding value of the preparation, and therefore in its road-building properties.

When employing this class of asphaltic-oil emulsions it is customary to give the road either one treatment or else two, with a short interval between, of a 15 to 18 per cent solution. The surface is thus thoroughly impregnated with the asphaltic binder, and as the emulsifying agents are more or less volatile, an insoluble and almost waterproof deposit is finally formed upon drying. This binder is not easily removed by rains or traffic, and if weaker solutions containing about 5 per cent of the original emulsion are applied from time to time the dust will be well laid. At the end of a season the road should not only be in better condition than at the beginning, but its wearing quality should be more or less permanently improved, according to the amount of binder which has been retained. These emulsions can be purchased for about 16 cents per gallon in concentrated form, and are usually contained in iron drums holding 120 gallons each. In the first treatments 1 gallon of the original emulsion is applied to about every 30 square yards, and for succeeding treatments the same amount is made to cover from 60 to 90 square yards, according to the strength of solution employed. The total cost per square yard during an average season will run from 4 to 6 cents, according to locality and traffic conditions. While this is somewhat higher than the cost of treating with soap emulsions of oil, the results obtained are more permanent, and this fact should be taken into account when comparing the two. Up to the present time the oil emulsions have been used principally upon parkways and suburban roads, as the cost of frequent treatment precludes their use on rural highways.

The next type, the tar emulsions, have up to the present time been more generally used in France, England, and Germany than in our own country. A number of these preparations are sold under trade

names and several have been patented. In their simplest form they differ from the oil emulsions only in the fact that coal-tar bitumens are employed in place of the asphaltic bitumens. Coal tar emulsified by means of ammonia and crude carbolic acid might be mentioned as a parallel preparation to the oil emulsion just described. The method of application and results obtained are practically the same as for oil emulsions. At the present time it is impossible to determine the relative value of different oil and tar emulsions. Nearly all of those which have been tried have proved to be effective temporary dust layers, but a number of competitive experiments under similar conditions would be required to determine which is capable of producing the most permanent results at the least expense. At the present time tar emulsions sell for about the same as oil emulsions.

During the past year a tar-preparation competition was held in England in connection with the motor dust trials and spreading-machine competition which have already been mentioned.[a]

Besides the two simple types of emulsions which have so far been considered, many others have been tried, and before leaving the subject it may be well to describe briefly some of them for the purpose of showing how many different materials have been used. It is impossible to classify them satisfactorily owing to their heterogeneous composition. No very systematic arrangement can therefore be followed in describing them.

Glue and bichromate of potash have in some instances been added to an oil or tar emulsion to cause it to harden upon the road surface. Under the action of light this preparation is claimed to become insoluble. Acid-treated cotton-seed oil and tar, emulsified by the action of caustic soda, is another type. A carbolic-acid oil emulsion to which has been added asphalt tar and the residue from glycerin distillation is also on the market. A caustic potash emulsion of coal tar, creosote, pitch, and resin has been patented. There are also a number of English, French, and German preparations which form emulsions with water, but their composition is kept secret by the manufacturers. A Scotch preparation composed of wool grease, soap fats, and potash is sold. A French compound of powdered asphalt and water has also been used. An emulsion of asphalt and creosote with water is another French compound, and there are many others, in some of which wood tar is employed.

A number of patents have been taken out in this country on preparations of various compositions, many of which are interesting because of the fact that waste products from different sources are utilized. One of these patents covers an emulsion of tar or oil to which casein has been added. Another makes use of the water lyes

---

[a] Loc. cit., p. 18.

obtained from wood-pulp factories. These water lyes are for the most part waste products; they contain resinous and salt ingredients which form not only binding but more or less hygroscopic compounds upon evaporation.

The fat or grease obtained from wool scourings, when emulsified with deliquescent salt solutions and sometimes creosote, is made the basis of another patent. And still another covers the application of an oil emulsion containing a deliquescent salt and a waste sulphite cellulose liquor produced in the manufacture of paper from wood pulp. The use of waste-molasses solutions, as well as mixtures of saccharine materials and lime, which form adhesive calcium saccharates, has also been suggested.

Nearly all of the materials and preparations described in this bulletin have some desirable qualities, and it is extremely difficult to make a selection among them. In general it may be said that those substances which can be applied in their natural condition have an advantage over the emulsions in the fact that their use is not dependent upon a constant water supply. On the other hand, they are more bulky to store, and transportation charges are proportionately greater than for the special preparations which are sold in a concentrated state. In regard to the emulsions themselves, it would seem that the mechanical emulsion, if it can be properly made and applied, may in some cases prove more desirable than the chemical emulsion, as no nonbinding emulsifying agents are required and the original binding material remains for the most part unaltered. Where strong alkalies, such as soda or potash, are used in connection with asphaltic material in particular the high binding bitumens are apt to be split up into substances of lower binding value. This fact has been practically demonstrated by the results obtained from the use of asphaltic oils upon alkali soils, as has been previously noted.

The use of these temporary binders in road construction is advocated by some experimenters. While somewhat better results may be obtained by this means than by the use of water alone, it is very doubtful if they will prove to be economical or of a very lasting character when the small proportion of binding material present in most of these preparations and emulsions is taken into account. In cases, however, where the material approaches the permanent binders in character and quantity of base present this criticism would not apply. It would seem, however, in any event that the use of a sufficient amount of permanent binder would be preferable when application is to be made during construction, as a better bond between the fragments of road metal is formed than when a water solution of the binder is employed.

THE SELECTION OF DUST PREVENTIVES.

IMPORTANCE OF CAREFUL SELECTION.

It is undoubtedly true that thousands of dollars are wasted annually in a repetition of experiments which have time and again proved costly mistakes. On the other hand, experiments which have given good results in some places have also proved failures when tried in different localities. It is necessary, therefore, not only that the experience of others be considered, but that some thought be given to the probable effect of local conditions upon the results which have in general been obtained. The importance of ascertaining the composition and quality of the material employed has already been dwelt upon at some length in considering the different preventives. While these are most important points, they are by no means the only ones to be taken into account. Differences in composition and physical qualities will often explain the fact that under otherwise similar conditions both good and bad results have been obtained. Discrepancies in results, however, are often obtained under varying conditions, when the same material is employed in each case. The same may be said of the method of application, and narrowing the subject down in this manner we must eventually come to the conclusion that differences in local conditions over which the experimenter has no control are factors of too much importance to be disregarded. Great differences in conditions have, of course, generally been considered, but it is not always those clearly apparent that cause the greatest variance in the results.

Owing to lack of sufficient data by experimenters it is often a hard matter to correlate the results obtained to their actual causes, but upon reviewing the literature of this subject certain facts are indicated which if properly considered should be of some value to the experimenter who has not already learned by experience what material is best suited to the roads he has occasion to treat. It is the author's purpose here to present these facts in such form as to serve as a general guide to the selection of proper material, but it should be understood that they are intended as a guide only and in no sense are to be considered as hard and fast rules. In many instances the selection of a dust preventive may be influenced by a combination of conditions which would be impossible to foresee except in individual cases. Sometimes a choice of preventives may seem to be equally divided among a number of materials and experiment alone will determine which, if any, is the most suitable. In many cases the experimenter is handicapped by lack of funds so that the most suitable material can not always be obtained. In these cases a less suitable material will have to be employed although in the long run this will often prove more costly. Except in rare instances economy is

the most important point to be considered and while permanency of results is often synonymous with economy it is not always so.

The division of dust preventives into two classes, the permanent and the temporary binders, suggests in a general way the first point that should be considered in regard to selection. Taken in connection with the three great classes of roads—country, suburban, and city—it is at once evident that under ordinary conditions the permanent binders only are suited to the first of these for the reason that it is impracticable to treat long stretches of country road at comparatively short intervals of time. When employing temporary binders the road should not only be under constant observation so that applications may be made whenever necessary, but facilities should be such that the work may be quickly and efficiently performed. It is seldom that this condition of affairs exists on a country road. With respect to suburban and city roads and streets, however, no such restrictions exist in the majority of cases, and either class of binder may be employed.

CHOICE OF MATERIALS FOR TREATING COUNTRY ROADS.

Country roads may be divided into two general classes, hard and soft roads. The first class is represented by the macadam and other broken-stone roads and the latter by earth roads. Sand and gravel roads may also be included in the latter class, although in many cases they more nearly approach the broken-stone roads in point of hardness. Among the permanent dust preventives coal tar and the asphaltic or semiasphaltic oils are the only ones which can be used under ordinary conditions on account of expense. In the case of hard roads a choice of these two materials will exist, but in treating soft roads oils only have so far proved successful, and except for purely experimental purposes we are limited to this class of material.

The choice between oil and tar for use on a rural macadam road will depend upon several conditions. The first of these would ordinarily be the relative cost at the given location. Other factors, such as relative quality of the available materials, climatic conditions, condition of the road, character of the road metal, and amount and quality of traffic to which the road is subjected, should also be taken into account, and the method of application with reference to these conditions should be carefully considered. In view of the fact that most work of this kind has not been planned or carried on with sufficient forethought, a hypothetical example may be considered even at risk of entering into too much detail. The necessity of clearly illustrating this matter has been made evident to the writer not only from reviewing published descriptions of experiments, but from actual work along these lines.

For example, let us suppose that we have a stretch of rural macadam to treat for excessive dust. Our first effort should be to determine, if possible, any predominant cause for the excessive dust formation. Upon investigation we might find that the road material showed no cementing value, and if the road was exposed to but little motor traffic, a top dressing of some road stone with good binding quality might solve the problem satisfactorily. On the other hand, if motor traffic were heavy we should have to resort to the use of tar or oil, as no such stone road has so far proved able to withstand successfully the action of heavy mixed traffic. With regard to a choice of these materials we should first ascertain which is most easily available at reasonable cost. If a tar produced at a low temperature and containing a fair amount of good pitch base can be obtained, it might be chosen tentatively. If not, a good refined preparation might be purchased. In some localities an asphaltic or semiasphaltic oil might be more readily available, or a residual oil preparation, but in any event we should ascertain so far as possible the particular properties of the materials which we are considering and unconditionally reject those which for reasons that have already been discussed are almost sure to prove unsatisfactory. Thus a tar produced at high temperature, a paraffin petroleum, or a badly cracked residuum should be at once discarded, no matter now cheap or readily available it might be.

If climatic conditions were such that a surface application would be unlikely to last throughout the winter, and we were unable to rebuild the road so as to make it a bituminous macadam, it would prove most economical to apply only sufficient material to last through the dusty season. In this case a cold application of coal tar diluted with sufficient water-gas tar or oil to give it the proper fluidity might be made, or a crude semiasphaltic petroleum used in preference to a more expensive residuum. In climates where a long succession of alternate frosts and thaws occur throughout the winter accompanied by cold rains, a treatment of this sort will prove far less expensive than a surface application of heavier binding material. Under more favorable conditions, however, this would not be true, and applications of tar or oil requiring heat might be more economical. The condition of the road will often indicate the method of treatment and kind of material which should be employed. If the road is in fairly good condition a surface application is often all that is required. It should, however, be remembered that the function of a permanent binder is not to make a bad surface good, but to keep a good surface in good condition and where the road is badly torn up and raveled it will often prove better policy in the long run to reconstruct it with the addition of a bituminous matrix or else to resurface it with a heavy coat of bitumen-covered stone.

In a case of this sort a good coal tar reinforced with pitch is to be preferred unless a very heavy asphaltic oil can be secured. If either material can be obtained the character of the road metal may lead to decision in favor of one or the other. A hard but somewhat porous rock is to be preferred in either case, but perhaps more particularly in that of tar, which is less easily absorbed than oil.

The selection of dust preventives for a soft country road is somewhat restricted, owing to the fact that oil only can be employed. For the softer roads an oil containing even a relatively small amount of paraffin base is valueless as a premanent binder, and we are thus narrowed down to a choice between the exceptionally good semi-asphaltic oils, the true asphaltic oils, and the residuums obtained from each. The oil containing the greatest amount of asphaltic base is usually to be preferred, although this is not always true. In the case of ordinary clay or loam roads the presence of a greater amount of true oil is necessary than in that of sand and gravel roads, in order to prevent the surface from becoming powdery under the action of traffic. Badly cracked residuums should be avoided, even to the extent of using in preference a crude oil containing less asphaltic base. A very clayey soil should be modified by the addition of sand before treatment, and, as has been noted, measures should be taken to overcome the effect of alkali soils upon the oil used. Methods of application suitable to various conditions have been discussed elsewhere and need not be considered here. Where gravel roads are to be treated it is not always necessary to employ an extremely heavy asphaltic oil, although such a material is to be preferred. Where fairly heavy crude semiasphaltic or residual oils can be obtained at a low figure they may often be used to advantage. And while the results may not be quite so permanent, the reduction in cost as compared with the true asphaltic oils will, under present conditions, more than compensate this difference, especially in the Eastern States.

CHOICE OF MATERIALS FOR TREATMENT OF SUBURBAN ROADS.

There is a wider selection of dust preventives possible in the treatment of suburban roads. Here all types of permanent and temporary binders may compete, and it is often a difficult matter to choose the best material. As most of the conditions governing the selection of permanent binders have already been mentioned, it is only necessary here to consider conditions influencing the selection of temporary binders, should a choice in their favor be made over permanent binders.

If a system of hydrants be located at convenient distances along the road, salt solutions or emulsions can be most easily employed; if not, recourse must be had to one of the lighter oil or tar products. In the latter case that product which contains the greatest amount of

binding base per unit cost should be selected, unless it possesses other qualities which are particularly undesirable, such as a strong and disagreeable odor. If an emulsion or salt solution can be employed the character of the road material may determine which is the most suitable. Thus a hard road, on which the products of wear will be slight provided they are retained upon the surface, or one in which the cementing value of the rock dust is good, can be effectively treated with a solution of some salt, such as calcium chloride. Also, in cases where the climate is more or less humid, a deliquescent salt may give the most satisfactory results. When the climate is very arid, however, the salt will have to be fed with too many applications of water to make its use economical. In the case of a road built of very soft rock, which wears badly under traffic, the asphaltic oil emulsions or the heavy tar emulsions are to be preferred on account of the binding and road-building qualities which they possess. As a general rule, when it is particularly desirable to obtain a road-building emulsion, one containing a volatile saponifying agent might be selected in preference to the nonvolatile saponifers, especially in the case of an asphaltic oil product, where the binding base is apt to be permanently injured by the presence of fixed alkalies. The choice of other emulsions and light preparations will, in many cases, depend upon locality. Where waste products of a deliquescent or binding character can be obtained cheaply they may be utilized for the purpose of dust laying.

In cities and towns where the traffic is heavy and of a mixed character the heaviest permanent binders represented by solid preparations should undoubtedly be used, but unless their use is supplemented by the temporary binders dust prevention is almost an impossibility. This is to a great extent due to the fact that large quantities of dust from outside sources are brought upon the streets, which makes it necessary to apply a dust preventive at frequent intervals. As the permanent liquid binders in concentrated form can not be applied in this manner, for obvious reasons, recourse must be had to the temporary binders. The selection of solid preparations for construction purposes comes under the subject of pavements, and has been so exhaustively treated in numerous publications that it need not be discussed here.

TREATMENT OF PARK ROADS.

Before leaving the subject of selection, the treatment of city park roads should be considered briefly. Here, under ordinary circumstances, we have conditions somewhat different from those pertaining to any of the three classes of roads so far considered. In the first place, park roads are almost entirely given over to pleasure traffic. As they are subjected to little or no heavy teaming, they are usually of lighter construction than the ordinary road, and in many cases

are composed of rather soft material. Motor traffic is likely to be excessive, and some suitable dust preventive is often needed.

Permanent binders may be used to advantage in many cases, but as a general rule more economical and satisfactory results can be obtained with temporary binders. Soap solutions or emulsions of asphaltic or semiasphaltic oils have given good results at small expense in a number of instances where emulsifying plants have been established in or near the park. Other forms of emulsion, as well as salt solutions, have also proved effective, but usually at a somewhat greater cost. When soap solutions of oil are employed it is necessary to give the road more attention than when heavier binding emulsions are used, especially in cases where considerable loose material occurs upon the road. The reason for this has already been considered, and it is only necessary to add that it does not constitute a serious objection when applied to park roads, as facilities are usually such that the work can easily be handled. A choice between permanent and temporary binders for use on park roads may depend upon any one or more of the conditions already mentioned for the various other classes of roads, but in particular where dust from outside sources is likely to be carried upon the road in considerable quantity the temporary binders are to be preferred.

METHODS OF EXAMINATION AND TENTATIVE SPECIFICATIONS FOR DUST PREVENTIVES.

It is always well when selecting a dust preventive to make as complete an examination of the material as possible. As this often necessitates a chemical analysis, however, which is sometimes difficult to make, a few easy tests have been selected which will give a fair indication of the dust-laying and road-building properties of the material under examination. Most of the methods described may be used by any person with the aid of a few simple appliances which will be described under the different tests. The more difficult analyses have been omitted, but references have been given for the use of those who may desire to use them. There are, at present, no standard methods for the examination of dust preventives. In rare instances experimenters have made attempts to ascertain the properties of the materials which they have had occasion to employ and in some cases have formulated specifications for their own use, but in general this branch of the work has been neglected. Considerable research is required before entirely satisfactory methods of examination and specifications can be decided upon, and it should be understood that the following are offered as a guide only. Investigations are now being conducted along these lines both in the laboratory and in the field, and it is the intention of the Office as soon as possible to present the subject in greater detail.

THE EXAMINATION OF TARS.

SPECIFIC GRAVITY.

The most convenient method of determining the specific gravity is by means of a thin spindle hydrometer. These hydrometers, graduated in direct specific gravity readings, may be obtained from any dealer in chemical apparatus at small cost, either singly or in sets. One ranging from 1.000 to 1.200 is most suitable for water-gas tar and crude coal tar. The refined tars, however, and those to which pitch has been added, may run somewhat above 1.200. When the tar is too viscous to allow the hydrometer to settle properly it is either necessary to dilute it with a known proportion of some lighter material, such as coal tar benzol, or else to weigh a known volume of the material.

If the former method is employed it is of course necessary to predetermine the specific gravity of the benzol used. As an example, we may take a very viscous coal tar and mix it thoroughly with an equal volume of coal tar benzol of say 0.880 specific gravity. The hydrometer might then show the specific gravity of the mixture to be 1.050. By multiplying this value by 2 and subtracting the specific gravity of the benzol we should obtain a fairly accurate determination of the specific gravity of the original tar as follows: $(1.050 \times 2) - 0.880 = 1.220$. Unless the hydrometer is graduated to read at a different temperature all specific gravity determinations should be made at ordinary temperature; that is, about 68° F. or 20° C.

By weighing a known volume of the tar and dividing this weight by that of an equal volume of water its specific gravity may also be determined.

While in itself the specific gravity determination is of little service in determining the actual properties of the tar, it indicates certain facts which, taken in connection with other tests, often prove of considerable value. In general the higher the specific gravity the more pitch will be present, but free carbon is also apt to be found in greater quantity. While coal tar varies from 1.10 to 1.20, it is seldom that one is found under 1.12. If the specific gravity is lower than this the presence of lighter products, such as water-gas tar or oil-gas tar, may be suspected. A refined tar should have a specific gravity of at least 1.18, or otherwise it is apt to be deficient in pitch. Owing to the presence of a greater proportion of heavy oils, a refined tar may contain less pitch than a crude product, even though its specific gravity is higher.

BOILING TEST.

The boiling test may be made by heating a quantity of the tar in an open vessel and by the use of a thermometer, noting the point at which it boils and also whether or not it shows a tendency to foam.

A determination of the boiling point is of value in distinguishing between a crude and a refined product. Crude tars invariably contain water, which causes them to foam when heated to their boiling points, which may run from 190° or lower to about 212° F. Dehydrated tars, or those from which the water only has been removed, will not foam, but their boiling point will be but little over 212° F. They can therefore be distinguished from the truly refined tars, which usually have a higher boiling point, owing to the removal of the second light and carbolic oils.

DISTILLATION OR FRACTIONATION TEST.

The fractional distillation of coal tar requires special apparatus and a certain amount of skill, which can be acquired by experience only in order to obtain satisfactory results. A detailed description will be found in the work by Allen.[a] In general it is carried on in much the same manner as the refining of coal tar, which has been described (see page 12). The operation is, of course, conducted on a miniature scale.

By this means the approximate composition of the tar is determined and the proportion of the various fractions ascertained. When examining a specially prepared or refined tar in this manner, a general idea may also be obtained as to how the preparation has been made and what effect has been produced upon the character of the binding base. Unless this test is conducted with great care, however, the results are apt to be misleading.

TEST FOR COAL-TAR PITCH.

The hardness of coal-tar pitch may be roughly determined in the following manner: Soft pitch softens at about 104° F. and melts at about 140° F. It can be easily kneaded between the teeth. Moderately hard pitch softens at about 140° F., melts at about 176° F., and can be kneaded with difficulty between the teeth. Hard pitch softens at about 176° F., melts at about 248° F., and crushes to powder.

In preparing a tar for road-construction purposes it is often desirable to reinforce its binding qualities by the addition of pitch. A soft pitch is the most suitable for this purpose, as it is more readily dissolved by the tar and contains a greater proportion of heavy life-giving oils than the harder pitches.

---

[a] Allen, A. H. Commercial Organic Analysis, v. 2, pt. 2.

DETERMINATION OF FREE CARBON.

The determination of free carbon in coal tar and coal-tar pitch can not be carried on well outside of a chemical laboratory. No entirely satisfactory method has yet been devised, but a close approximation can be made by digesting from 2 to 5 grams of the material over night with about 150 c. c. of coal-tar benzol. By this means all of the soluble bitumens are diluted to such an extent that they may be filtered from the insoluble carbon which remains in suspension. The solution is decanted upon a weighed Gooch crucible, the bottom of which is covered with an asbestos felt. By means of a vacuum it is filtered into a suction flask, the residue washed into the crucible with coal-tar benzol, and the washing continued until the filtrate runs clear. The crucible is then heated until all the benzol is driven off, and after cooling is weighed. The additional weight represents the free carbon, which should be calculated upon a percentage basis. Free carbon may also be determined by means of a Soxlet extractor.

The presence of an excessive amount of free carbon in coal tar and coal-tar pitch is detrimental to the binding power of the material. Owing to a lack of data it is impossible at the present time to decide just how much carbon should be allowed. It is always present to some extent in both the tar and the pitch, no matter how carefully they may have been prepared. When high temperatures have been employed in their production, however, the carbon content will be excessive, and for this reason mainly the use of high-temperature products should be avoided. The determination of free carbon is most important and should be made when possible and the percentage noted in a statement of the results obtained from the use of any particular tar. By this means a better idea may be formed as to how much carbon may be present without seriously affecting the results. Other things being equal, it is safe to say that the best results will be secured from the use of that product containing the least free carbon.

DETERMINATION OF NAPHTHALENE, ANTHRACENE, ETC.

No very accurate method of determining these substances on a small scale has been devised. Some idea may be obtained of the relative quantities present in any two materials by comparing the amount of solids found in the distillates produced by fractionation. Refined tars, as a rule, have had a portion of these substances removed, and in this respect are to be preferred to the crude products.

SUGGESTIONS FOR SPECIFICATIONS FOR THE QUALITY OF COAL TARS TO BE USED AS DUST PREVENTIVES OR ROAD PRESERVATIVES.

It has been shown that tar and tar preparations may be used in any one of four ways: as temporary binders, semipermanent binders, permanent binders applied to the surface of a road, or as permanent

binders in road construction. It is evident, therefore, that different specifications should be made according to the different uses.

I. When used as a temporary binder it is usually employed in the form of an emulsion, and at present it is impossible to frame any satisfactory specifications, owing to the fact that many of these emulsions contain other binding materials besides tar.

II. When used as a semipermanent binder it is necessary that sufficient binding base be present to last throughout a dusty season, and, for reasons of economy, that the material be sufficiently fluid to apply cold. For this purpose the following specifications may be tentatively made:

1. The coal tar should be one formed at a comparatively low temperature, such as that produced from by-product coke ovens or by gas plants which use no enriching materials for increasing the illuminating value of their gas.

2. A crude tar may be employed for this purpose because of its cheapness.

3. If not sufficiently fluid to apply cold, enough water-gas tar may be added to bring it to the proper consistency, but the proportion of the latter should not exceed 50 per cent of the mixture.

III. When used as a permanent binder for surface application either a crude or a refined product may be employed, preferably the latter.

1. If a crude coal tar is selected, it should have the following properties:

(*a*) Same as II, 1.

(*b*) Its specific gravity should be not lower than 1.15 nor higher than 1.19.

(*c*) It should be free from water-gas tar and oil tar.

2. If a refined tar is selected, the following might be specified:

(*a*) Same as II, 1.

(*b*) The specific gravity should be not lower than 1.17 nor higher than 1.20.

(*c*) No water nor ammoniacal liquor should be present, and the boiling point should be above 110° C. (230° F.).

(*d*) Upon distillation at least 40 per cent by volume of pitch should remain after all oils have been driven off below 270° C. (518° F.).

IV. When used as a permanent binder in road construction it is necessary that more binding base be present than is usually found in the crude product. A refined product should therefore be employed. This may either be prepared from a crude tar by the contractor or else a special preparation may be purchased.

1. In the former case a mixture may be prepared as follows from a crude tar, which meets the specifications set forth in III, 1:

(*a*) The tar should be heated until the boiling point is raised to at least 110° C. (230° F.).

(*b*) One-tenth part or more of good soft pitch should then be dissolved in the tar while hot. The quantity of pitch added should be sufficient to produce a pitch residue of at least 50 per cent by volume after all oils have been driven off under 270° C. (518° F.).

2. A refined tar for this purpose should meet the same requirements as suggested for III, 2, except that the pitch remaining after volatile oils under 270° C. (518° F.) have been driven off should amount to at least 50 per cent by volume.

In some cases, especially where the climate is warm throughout the year, a tar considerably richer in pitch may be preferred. As a rule, low-temperature tars may conveniently contain more pitch than those produced at high temperatures, owing to the presence of a greater amount of heavy oils and a smaller amount of free carbon.

THE EXAMINATION OF MINERAL OILS.

SPECIFIC GRAVITY.

The specific gravity of oils may be determined in the same manner as has been described for tars. If it is necessary to dilute the oil in order to obtain a reading with the hydrometer, gasoline or kerosene of known density should be used as a dilutant. A set of hydrometers ranging from 0.700 to 1.000 is usually sufficient for this purpose.

In connection with other tests, a specific-gravity determination is of value as indicating the proportion of heavy binding oils present in the material examined. It is also of value in differentiating between the various kinds of oils, as described on page 27.

FLASH POINT.

The use of a special device, such as the New York State oil tester, will give the most accurate flash-point determinations, but for ordinary purposes the following method will usually serve: A beaker of about 250 c. c. capacity is half filled with the oil to be tested and gradually heated by means of a low-flame Bunsen or other suitable burner. From time to time the small flame from a capillary tube connected to the gas supply is passed just above the surface of the oil and the temperature at which the oil vapor flashes is noted by means of a thermometer, which should be immersed in the oil. The thermometer should not rest upon the bottom of the beaker, but should be suspended from a support placed above.

The flash point of an oil indicates its most volatile oil constituent, and in a measure serves to differentiate not only between crude and refined products, but between many varieties of each class. It also serves to point out the extent to which a refined oil has been distilled.

VISCOSITY.

The relative viscosity of oils at a given temperature may be determined by means of special devices known as viscosimeters, descriptions of which will be found in a work by Allen.[a]

While the values obtained by viscosity determinations are purely arbitrary, they indicate the relative rate of flow, and therefore in some measure the adaptability of oils to different methods of application—i. e., cold or hot, and if hot, at what temperature.

GASOLINE TEST FOR WATER AND IMPURITIES.

Oils carrying a considerable amount of water and other impurities which can not be separated by settling may be diluted with gasoline in a graduated cylinder and allowed to stand for twenty-four hours, or until the water and impurities settle to the bottom. If a known volume of oil is taken, a rough determination of the impurities may be made by noting the volume of these impurities as indicated by the graduate.

By means of this determination the actual amount of oil present is indicated, and deductions can be made for the impurities, which should not, however, be present to any great extent.

VOLATILITY TEST.

The volatility test may be made in either one of two ways. The first is to determine the percentage loss in a sample of known weight and surface area when subjected to a known temperature for a given length of time, the character of the residue also being noted. By the second method the percentage loss is determined when the residue has acquired certain definite properties.

If the first method is employed, 20 grams of the oil is weighed into a crystallizing dish 2¼ inches in diameter and 1¼ inches high and heated in a drying oven for seven hours at 400° F. Upon cooling, the percentage loss in weight is noted and the residue examined. Asphaltic residues should be smooth and if warmed sufficiently should pull out to a thread. Those containing paraffin are somewhat granular, and if much is present will not pull to a thread. They are also more or less greasy to the touch. The consistency of the residue when cold is also noted, and if sufficiently dense its penetration may be determined by means of a penetrometer. Detailed descriptions of suitable drying ovens and penetrometers are to be found in a work by Richardson.[b] If the oil contains water and light oils it is often desirable to determine its volatility at other temperatures, such as 212° F. and 325° F. By this means an idea of the relative quantities of these materials may be obtained.

---

[a] Allen, A. H. Commercial Organic Analysis, vol. 2, pt. 2.

[b] Richardson, Clifford. Modern Asphalt Pavement.

The second method has been used to some extent in the examination of California oils, and consists in heating a weighed sample in a hot-air oven at 400° F. until it is reduced to what is known as "D" grade asphalt, having a penetration of 60°.

By means of the volatility test the amount of heavy base present in an oil may be determined as well as its value as a binder. While the conditions of the test are in no sense identical with those upon the road a fair idea may be obtained as to the behavior of an oil upon the road.

NAPHTHA-SOLUBLE BITUMEN.

The determination of naphtha-soluble bitumen is made in the same manner as for the determination of free carbon in coal tar, except that in this case 5 to 10 grams of the oil is digested with 100 cc. 88° Baumé naphtha. After the residue upon the filter has been weighed it may be ignited until all organic matter has been driven off and the inorganic matter weighed when cool. The difference between this weight and that of the first residue will give the amount of organic matter insoluble in naphtha.

This determination is of special value when applied to refined oils, as the percentage of naphtha-insoluble organic material is an indication of the amount of cracking which has taken place during the process of refining.

TOTAL BITUMEN DETERMINATION.

The determination of total bitumen may be made by treatment of the oil with carbon bisulphide in a manner similar to that described for the determination of naphtha-soluble bitumen.

By noting the difference between the naphtha-soluble and the carbon-bisulphid-soluble bitumens, an idea may be obtained of the percentage of asphaltine-like hydrocarbons which tend to harden the residue.

DETERMINATION OF PARAFFIN.

The determination of paraffin may be made according to Richardson's [a] modification of the method of Holde. It is a tedious and difficult determination, and is not often required for an ordinary examination of a dust preventive, as the character of the residue obtained from the volatility test will indicate whether or not too much paraffin is present.

SPECIFICATIONS FOR MINERAL OILS TO BE USED AS DUST PREVENTIVES OR ROAD PRESERVATIVES.

As oils may be used on almost any kind of road either as temporary or permanent binders, their requisite qualities will depend upon the use to which they will be put. Almost any asphaltic or semiasphaltic oil will prove satisfactory as a temporary binder if properly applied either in the form of an emulsion or in its natural state. Specifications for the properties of permanent binders only will therefore be considered.

---

[a] Richardson, Clifford. Modern Asphalt Pavement, p. 519.

According to Ellery a good road oil should contain at least 40 per cent of commercial "D" grade asphalt, having a penetration of 60° and no more than 3 per cent of foreign matter and water. When employed in the construction of oiled graveled streets at Los Angeles, Cal., the following specifications [a] were adopted for crude oil:

The specific gravity shall not be lower than 10° (1.000) nor higher than 11° Baumé (0.993).

All crude petroleum shall contain not less than 70 per cent "D" grade asphalt, California standard.

All crude petroleum shall be tested for water and sediment. Deductions for water and sediment in crude petroleum will be made in exact proportion to the percentage of such water and sediment found.

In the construction of asphaltic oiled and tamper-rolled dirt roads at Santa Monica, Cal., the following characteristics were specified:

The oil shall be from 12° to 14° Baumé (0.986–0.972) test at a temperature of 60° F. and contain not less than 70 per cent of pure liquid asphaltum, natural nonprocessed oil to be subject to gasoline test for water and foreign matter, and not to contain over 2 per cent of water or foreign matter.

From experiments conducted by the Office of Public Roads it would seem that only reduced or residual oils are apt to prove satisfactory as permanent binders if they are semiasphaltic in character. The following specifications are therefore suggested for this class of oils:

1. The oil shall have a specific gravity of not less than 0.95.
2. Its flash point shall be not lower than 300° F.
3. It shall be free from water as determined by the gasoline test.
4. When heated to 400° F. in the manner previously described for seven hours its loss in weight should not be over 35 per cent. The character of the residue should be smooth and nearly solid when cold, but not so hard that it may not be easily dented with the finger, and when soft it should pull to a long, thin thread.
5. The oil shall be soluble in carbon disulphide to the extent of 98 per cent, and in 88° naphtha to at least 88 per cent.

The methods of examination and specifications for asphalt and other solid materials have not been considered in this chapter for obvious reasons. They belong to works on the subject of pavements. In conclusion it may be said while specifications for dust preventives and road preservatives should prove of great service in most cases in securing proper materials they are of no value unless the proper method of applying the material to the road is employed. So far as possible these methods have been outlined in this bulletin, but local conditions will often necessitate modifications, and much will therefore depend upon the experimenter or overseer of the work.

[a] Biennial Report of the Dept. of Highways of California, 1906, p. 44.

INDEX.

O